The CANADIAN FIELD-NATURALIST

A JOURNAL OF FIELD BIOLOGY AND ECOLOGY

Promoting the study and conservation of northern biodiversity since 1880

Volume 134, Number 1 • January–March 2020

Ottawa Field-Naturalists' Club
Club des naturalistes d'Ottawa

The Ottawa Field-Naturalists' Club

FOUNDED 1863 (CURRENT INCORPORATION 1879)

Patron

Her Excellency the Right Honourable Julie Payette, C.C., C.M.M., C.O.M., C.Q., C.D.
Governor General of Canada

The objectives of this Club shall be to promote the appreciation, preservation, and conservation of Canada's natural heritage; to encourage investigation and publish the results of research in all fields of natural history and to diffuse information on these fields as widely as possible; to support and cooperate with organizations engaged in preserving, maintaining, or restoring environments of high quality for living things.

To communicate with the Club, address postal correspondence to: The Ottawa Field-Naturalists' Club, P.O. Box 35069, Westgate P.O., Ottawa, ON, K1Z 1A2, or e-mail: ofnc@ofnc.ca. For information on club activities, go to www.ofnc.ca.

The Canadian Field-Naturalist

The Canadian Field-Naturalist is published quarterly by The Ottawa Field-Naturalists' Club. Opinions and ideas expressed in this journal do not necessarily reflect those of The Ottawa Field-Naturalists' Club or any other agency.

Website: www.canadianfieldnaturalist.ca/index.php/cfn

All manuscripts intended for publication—except Book Reviews—should be submitted through the online submission system at the CFN website: http://www.canadianfieldnaturalist.ca/index.php/cfn/user. Click the "New Submission" link on the right side of the webpage and follow the prompts. Authors must register for a cfn account at http://www.canadianfieldnaturalist.ca/index.php/cfn/user/register in order to submit a manuscript. Please contact the Online Journal Manager (info@canadianfieldnaturalist.ca) if you have any questions or issues with the online submission process. In only rare, exceptional circumstances will submissions other than online be considered and, in these cases, authors must contact the Editor-in-Chief (editor@canadianfieldnaturalist.ca) prior to submission. Instructions for Authors are found at https://www.canadianfieldnaturalist.ca/public/journals/1/CFN-author-instructions20Sept2019.pdf.

The Thomas H. Manning fund, a special fund of the OFNC, established in 2000 from the bequest of northern biologist Thomas H. Manning (1911–1998), provides financial assistance for the publication of papers in the CFN by independent (non-institutional) authors, with particular priority given to those addressing Arctic and boreal issues. Qualifying authors should make their application for assistance from the fund at the time of their initial submission.

Book-review correspondence, including arranging for delivery of review copies of books, should be sent to the Book Review Editor by e-mail: bookrevieweditor@canadianfieldnaturalist.ca.

Subscriptions and Membership: Subscription rates for individuals are $40 (online only), $50 (print only), or $60 (print + online). Libraries and other institutions may subscribe for $120 (online only or print only) or $180 (print + online). All foreign print subscribers and members (including USA) must add $10 to cover postage. The Ottawa Field-Naturalists' Club annual membership fee of $40 (individual), $45 (family), or $20 (student) includes an online subscription to *The Canadian Field-Naturalist*. Members can receive printed issues of CFN for an additional $30 per volume (four issues). For further details, see http://ofnc.ca/membership-and-donations. The club's regional journal, *Trail & Landscape*, covers the Ottawa District and regional Club events and field trips. It is mailed to all club members. It is available to libraries at $40 per year. Subscriptions, applications for membership, notices of changes of address, and undeliverable copies should be sent to subscriptions@canadianfieldnaturalist.ca or mailed to: The Ottawa Field-Naturalists' Club, P.O. Box 35069, Westgate P.O., Ottawa, ON, K1Z 1A2 Canada. Canada Post Publications Mail Agreement number 40012317. Return postage guaranteed.

COVER: Adult Eastern Elliptio (*Elliptio complanata*) firmly attached to the foot of an adult Eastern Painted Turtle (*Chrysemys picta*), Plymouth County, Massachusetts, USA, 23 September 2014. See the article in this issue by Jones *et al.* pages 56–59 about other observations of passive transport of mussels and a fingernail clam by turtles. Photo: M.T. Jones.

The Canadian Field-Naturalist

Invertebrate settlement and diversity on a glass sponge reef

Stephanie K. Archer[1,2,*], Glen Dennison[3], Lora Tryon[4], Sheila Byers[5], and Anya Dunham[1]

[1]Fisheries and Oceans Canada, Pacific Biological Station, 3190 Hammond Bay, Nanaimo, British Columbia V9T 6N7 Canada
[2]Current address: Louisiana Universities Marine Consortium, 8124 Highway 56, Chauvin, Louisiana 70344 USA
[3]Triumf, 4004 Wesbrook Mall, Vancouver, British Columbia V6T 2A3 Canada
[4]Lake Trail Environmental Consulting, P.O. Box 1746, Garibaldi Highlands, British Columbia V0N 1T0 Canada
[5]Beaty Biodiversity Museum, University of British Columbia, 2212 Main Mall, Vancouver, British Columbia V6T 1Z4 Canada
*Corresponding author: sarcher@lumcon.edu

Archer, S.K., G. Dennison, L. Tryon, S. Byers, and A. Dunham. 2020. Invertebrate settlement and diversity on a glass sponge reef. Canadian Field-Naturalist 134(1): 1–15. https://doi.org/10.22621/cfn.v134i1.2297

Abstract
Glass sponge reefs are an ecosystem unique to the continental shelf of the northeast Pacific Ocean. Due to their vulnerability and limited distribution, several sponge reef protection initiatives exist within Canadian waters with the common goal of conserving biodiversity. To date, the biodiversity associated with sponge reefs has largely been assessed using remote video methods that allow us to describe large fauna associated with the reefs. However, small organisms are typically missed, resulting in an underestimate of reef-associated biodiversity. In this study we aimed to further describe invertebrate biodiversity associated with sponge reefs. Sponge reefs recently discovered in Howe Sound, British Columbia are within safe recreational SCUBA diving limits allowing us to examine macrofaunal settlement timing and community structure using diver-deployed settlement plates. We examined the effect of settlement plate material and elevation above the benthos within the reef on invertebrate community structure. A total of 70 taxa settled on the plates representing 10 phyla, including two phyla not previously described on sponge reefs: Nemertea (ribbon worms) and Platyhelminthes (flatworms). There were no significant differences in taxa richness, diversity, or community structure associated with settlement plate material or height above the benthos. Ours is the first report of invertebrate settlement on a sponge reef in the Salish Sea and the first description of larval settlement timing for nine invertebrate species in the northeast Pacific.

Key words: Glass sponge reefs; invertebrates; Porifera; community structure; juvenile settlement

Introduction
Glass sponge reefs, an ecosystem unique to the continental shelf of the northeast Pacific Ocean, are found from the Salish Sea in the south to Portland Canal, on the Canada-Alaska border in the north (Conway *et al.* 1991; Stone *et al.* 2014; Dunham *et al.* 2018). The sponge reefs are large biogenic structures that play an important role in carbon, nitrogen, and silica cycling and support more diverse and abundant faunal communities than the surrounding sea floor (Chu and Leys 2010; Chu *et al.* 2011; Kahn *et al.* 2015, 2018; Maldonado *et al.* 2016; Dunham *et al.* 2018). The reefs are formed by three species of glass sponges: Cloud Sponge (*Aphrocallistes vastus*), *Farrea occa* (no common name and absent on reefs in the Salish Sea), and Goblet Sponge (*Heterochone calyx*). These sponges occur throughout the world but have only been reported to form reefs in the northeast Pacific. They can form reefs because they possess skeletons of fused silica spicules which maintain their three-dimensional structure after the sponges' death. The erect dead sponge skeletons serve as settlement substrate for juvenile sponges and are infilled with baffled sediment, a process that results in reef formation after multiple generations of sponges. While the sponge skeletons are rigid, they are fragile. Consequently, the sponges and reefs are vulnerable to damage from human activities that contact the bottom, such as trawl and trap fishing, and cable laying (Dunham *et al.* 2015; Kahn *et al.* 2016). Because of their vulnerability to human impacts and their limited global distribution the sponge reefs are a high conservation priority in Canada. As a result, one marine protected area (MPA) and 17 bottom contact fishing closures have been created to protect sponge reefs and the biodiversity they support (DFO 2015, 2019).

Despite the high priority of protecting biodiversity associated with sponge reefs, we have a limited under

standing of the life histories of many organisms residing on the reefs. In particular, we do not know when many of the organisms reproduce or when larvae settle onto the reefs. For example, the exact timing of spawning and larval settlement for reef-forming glass sponges is not known, although evidence points to at least one spawning period in the winter months for sponges in the Salish Sea (Kahn *et al.* 2016) and potentially multiple settlement periods in Hecate Strait (Guillas *et al.* 2019). Knowing when reef-associated fauna (including reef-forming sponges) recruit to the sponge reefs can help guide monitoring, management, and potential restoration activities in the future.

In addition to a lack of knowledge of the life history of reef-associated fauna, it is likely that our understanding of reef-associated biodiversity is incomplete. To date the biodiversity associated with sponge reefs has largely been assessed using remote video methods because most reefs occur outside safe recreational SCUBA diving limits (i.e., deeper than 40 m; but see Krautter *et al.* 2001; Cook 2005; Guillas *et al.* 2019). While remote video surveys allow us to describe large fauna (≥4 cm) associated with the reefs, smaller organisms (hereinafter referred to as macroinvertebrate fauna), such as polychaetes and bryozoans, are typically missed. Several of the reef complexes recently discovered in Howe Sound (Clayton and Dennison 2017; Dunham *et al.* 2018) are significantly shallower than other known reefs (22–127 m compared to 90–300 m), occurring within safe recreational SCUBA diving limits. The discovery of these shallow reefs allowed us, for the first time, to examine macrofaunal community structure and settlement timing on a glass sponge reef in the Salish Sea using diver-deployed settlement plates.

Juvenile settlement is driven by several factors, including water flow and the surface structure and chemistry of available substrate (Rodriguez *et al.* 1993). Because little is known regarding the settlement requirements for glass sponges and other reef-associated fauna we used two settlement plate materials (frosted glass and ceramic clay) in order to capture a wider range of organisms. We hypothesized that frosted glass plates would attract a more diverse and abundant community as this surface approximates the surface of erect dead sponges, the primary settlement surface available on sponge reefs. We positioned the sets of plates at different heights above the benthos as a proxy for water flow, as complex benthic habitats, like sponge reefs, create a benthic boundary layer where water flow is slowed (Grant *et al.* 2019). Determining whether elevation above the benthos impacts the diversity of benthic invertebrates settling on the reef has implications for reef conservation as well. When human activities damage sponge reefs they destroy the three-dimensional structure of the reef, often crushing or toppling both live and dead sponges. If a more diverse invertebrate community settles on plates higher above the benthos, this destruction of the three-dimensional structure may have larger impacts on reef-associated biodiversity than previously reported. We hypothesized that plates located higher above the benthos would attract a more diverse and abundant settler community as water flow around these plates should be higher. Overall, the goal for this study was to describe the biodiversity of small benthic invertebrates associated with sponge reefs and determine if settler diversity is affected by plate material and/or height above the benthos. Additionally, we report the first description of larval settlement timing for several invertebrate species in the northeast Pacific.

Study Area

Our study occurred at the Halkett Point glass sponge reef in Howe Sound, Salish Sea on the southwest coast of British Columbia (BC), within the Halkett Bay Provincial Marine Park northwest of the city of Vancouver (Figure 1a). The glass sponge reef was first discovered by G. Dennison in 1996 and first formally described by Clayton and Dennison (2017). The reef was federally protected from all bottom-contact fishing activities in 2019, but at the time of our study, in 2017, fishing restrictions were not yet in place (DFO 2019). The main sponge reef occurs between 22–90 m on a pinnacle that is irregular in shape with a relatively flat top and gently sloping sides (Figure 1b; Clayton and Dennison 2017; DFO 2018). Glass sponge reefs are naturally patchy with areas of live, erect dead, and buried dead sponge present throughout the reef (Dunham *et al.* 2018). At Halkett Point sponge reef live reef-building sponges cover 4% of the reef and 40% of the reef was classified as live reef habitat (i.e., live sponges dominate the benthos; Dunham *et al.* 2018); 31 associated species have been documented on the reef (DFO 2018; Dunham *et al.* 2018). Some rocky outcroppings are found on the western side of the pinnacle.

Methods

Tree design, deployment, monitoring, and retrieval

Two trees with eight settlement plates each were constructed using a 1.5 m length of 20 mm PVC pipe (sold as ¾ inch PVC pipe) for the stem with two sets of 0.30 m length PVC branches extending from the top and middle portions of the stem (Figure 2a,b). Each branch was further divided into two additional branches, each supporting a 0.11 m × 0.11 m × 0.03 m settlement plate made of either ceramic clay or frosted glass. Plates were fastened to the PVC branch with a

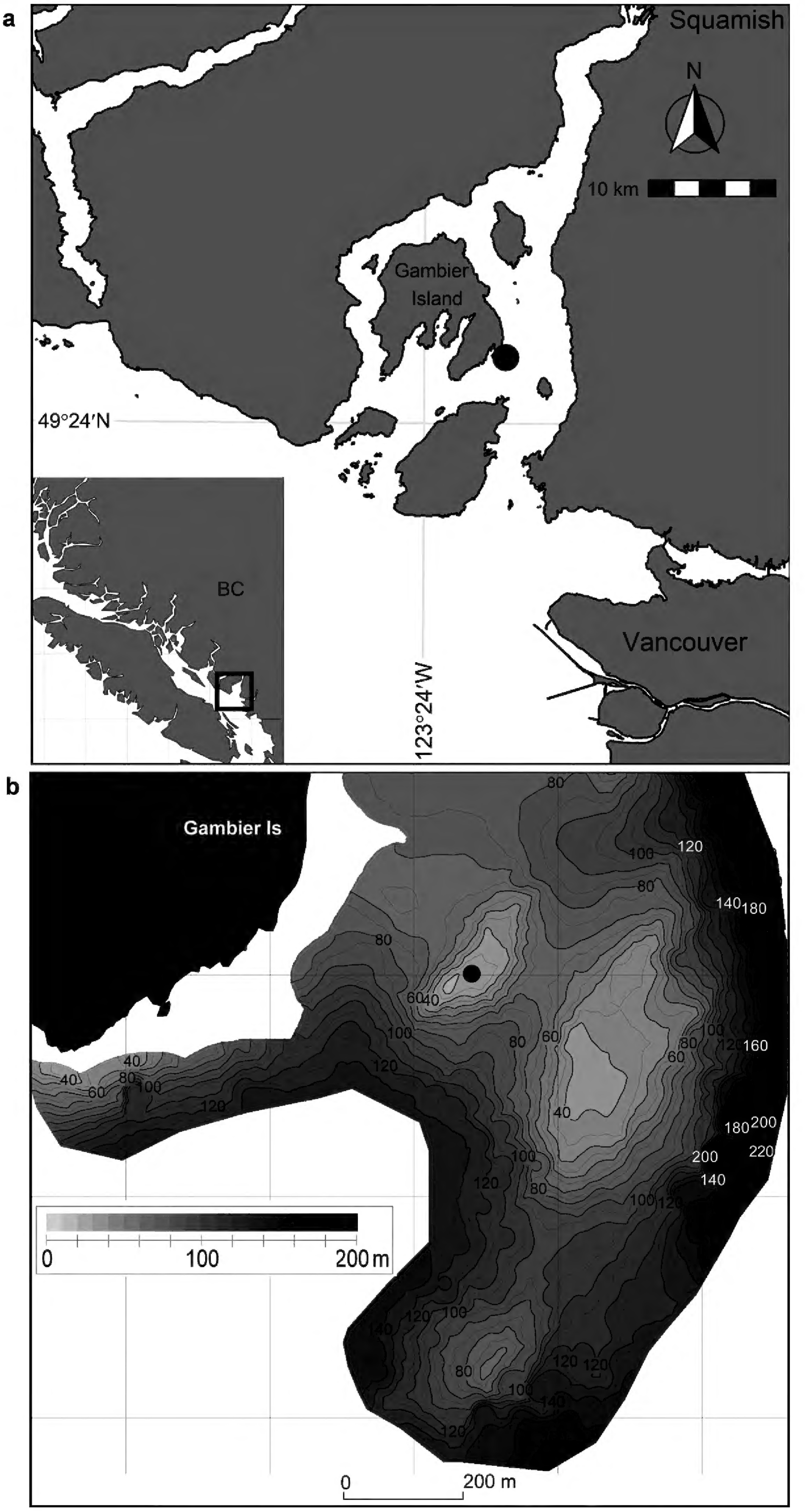


FIGURE 1. a. The location of the Halkett Point glass sponge reef as marked by the black dot, and b. a detailed bathymetric map of the reef area. Bathymetry contours were derived from a 3 × 3 m resolution survey of the area using downwards sonar conducted by G. Dennison. The location of the settlement trees is marked on b with a black dot.

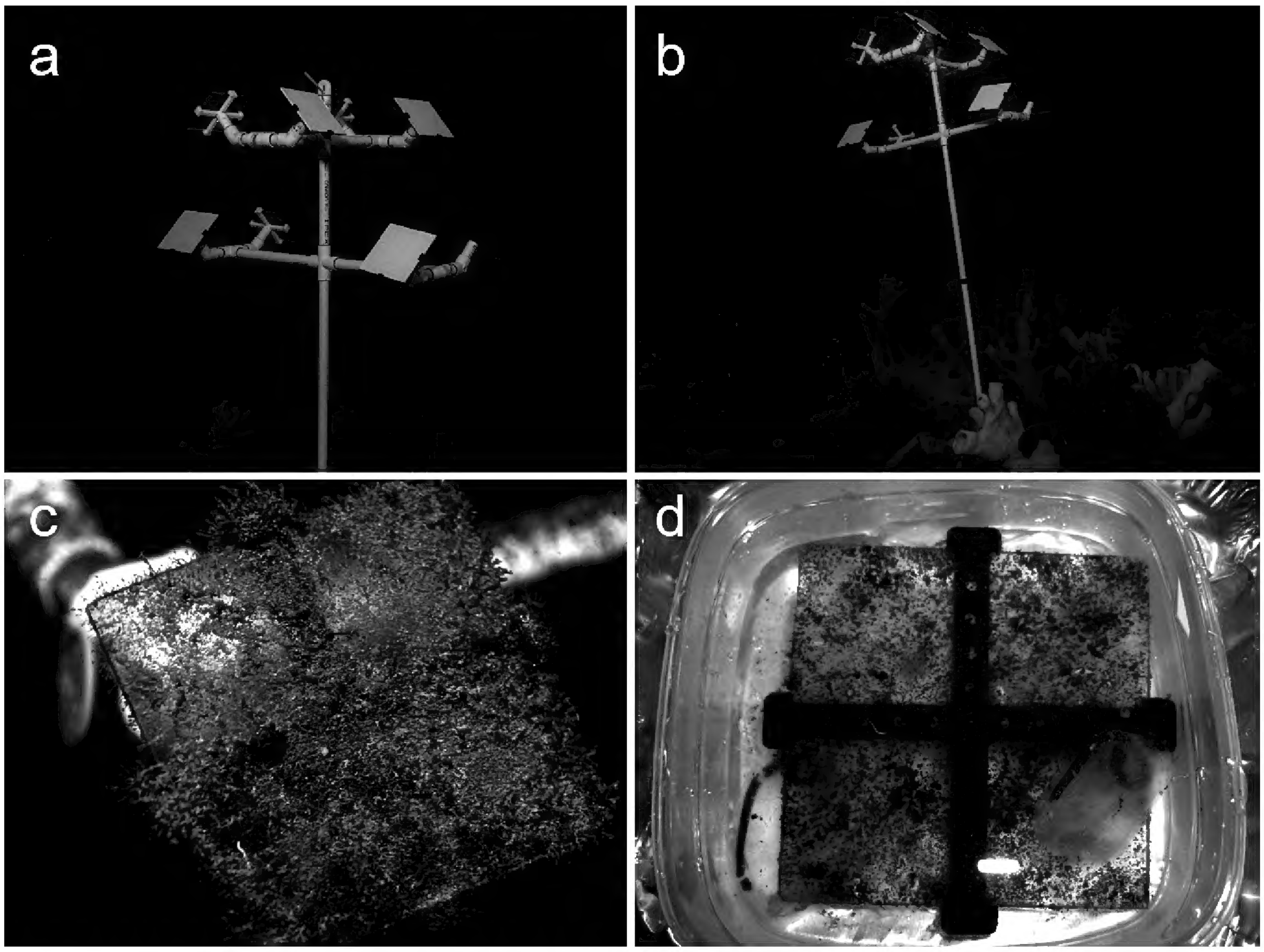


FIGURE 2. The settlement plate trees *in situ*: closeup (a) and with a landscape view (b). Plates were attached to the trees at the ends of the branches at a 45° angle. c. is an example of a plate *in situ* and d. is a plate after retrieval. Photos: Adam Taylor (a,b), Diane Reid (c), Sheila Byers (d).

plastic bracket (Figure 2a). Each tree was designed to hold two ceramic and two glass settlement plates on each of the upper and lower branches for a total of four of each plate type; the upper and lower branches were 24 cm apart. The brackets holding the ceramic and glass plates were designed in SOLIDWORKS® 3D mechanical CAD software Rev 2016 (Dassault Systèmes SolidWorks Corporation, Waltham, Massachusetts, USA) and produced with a Stratasys Mojo 3D printer (Computer Aided Technology, Buffalo Grove, Illinois, USA). The bracket was designed to allow for easy removal and installation of the plates. Each set of glass and ceramic settling plates was identified with a unique tag secured to the corresponding branch of the tree.

The trees were deployed 11.8 m apart on 4 March 2017. Trees were installed with settlement plates attached by penetrating the stem of the tree into the soft surface layer of the reef (e.g., Figure 2b). The trees were deployed in an area next to low-density sponge (31.7 m depth, hereinafter tree 1) with the lower branches ~0.5 m above the benthos and in an area next to high density sponge (at 33.5 m depth, hereinafter tree 2) with the lower branches ~0.65 m above the benthos.

A TidBit® v2 (Onset Computer Corporation, Bourne, Massachusetts, USA) temperature logger was attached to the lower branch of each tree to record temperature every 15 min over the course of the study. Data from both temperature loggers were collected from 12 March to 16 August 2017; the temperature logger attached to tree 1 failed to record from 16 August 2017 to 21 April 2018 and thus only data from tree 2 were available for this time period.

Monitoring of settlement on the plates was done with macrophotography. Divers visited the site on 9 July 2017, 16 August 2017, 2 December 2017, and 8 April 2018 to photograph the settlement plates. Photos were taken in a sequence that included an initial photo of the unique identifier tag followed by photos of the frosted glass and ceramic clay settlement plate associated with each tag; photos of the entire settlement plate and of each plate's surface were taken at a greater magnification. These photos were not used in our analysis as many of the taxa that settled on the plates are difficult, if not impossible, to identify even to phylum at this level of resolution. However, for slightly larger taxa (≥ ~2 cm) these photos serve as a permanent record of plate colonization and are available for future study (e.g., Figure 2c).

Settlement plates were retrieved on 8 and 21 April 2018 after ~13 months of immersion. Two plates were recovered on 8 April to test the protocol for plate recovery; the remainder were recovered in the next

available window of safe diving weather. Retrieval involved divers removing the brackets from the trees *in situ*, storing the brackets with the attached settlement plates in ambient seawater in a 870 mL sandwich container (LOCK&LOCKR HPL823, Lock & Lock, Seoul, South Korea) with a secure locking lid, and bringing them to the surface to be processed. Removal of the brackets was done by loosening a 11 mm nut that secured them to the tree branches. At the time of retrieval, it was discovered that tree 2 had fallen over and was leaning on a clump of adjacent sponge. The maximum duration when the tree was in this final position before retrieval was estimated to be three months based on the last observation of it standing upright. Four settlement plates were resting directly on a clump of sponge while the other four plates on the tree were not in contact with the sponge.

Community sampling

Once at the surface, the 16 containers with the individual plates were processed sequentially. Each container was placed inside a larger aluminum pan to capture any spillage of seawater as the lid was removed. Approximately three-quarters of the seawater in the container was poured through a 0.25 mm sieve to capture any macrofauna that had been dislodged during transport from depth to surface. These dislodged or 'mobile' macrofauna are herein referred to as flocculent. Container spillage in the aluminum catch-pan was also poured through the sieve. Photographs were taken of the top and bottom sides of the plate in a prepreservation state to assist with taxa documentation and identification (e.g., Figure 2d). The flocculent residue on the 0.25 mm sieve was returned to the original LOCK&LOCKR container using pre-filtered saltwater (0.25 mm sieve) along with a waterproof label identifying each plate. The container was then topped up with a 30% solution of 95% ethanol and pre-filtered saltwater to anesthetize macrofauna on the plate and in the flocculent. Several hours later, the anesthetizing fluid was decanted through a 0.25 mm sieve, the flocculent residue on the sieve returned to the container, and the container topped up with 95% ethanol. The lid of the container was securely relocked and placed into a cooler for transport to Biologica Environmental Services, Victoria, BC (a full-service aquatic taxonomy lab) for taxonomic identification. The preservation process was repeated for each of the 16 plates. The 0.25 mm sieve was washed with prefiltered seawater between processing of each bracketed plate.

Biologica taxonomists processed each plate by identifying and enumerating all organisms attached to the surfaces. All organisms were identified using a combination of dissecting (10–40×) and compound (100–1000×) microscopes and standard taxonomic keys to species or lowest practicable level. Either total abundance data (counts) or total percent cover was provided for all organisms, including solitary and colonial taxa, found attached to the top and bottom sides of each plate. Because it is often difficult, if not impossible, to identify individuals of colonial organisms, their abundance was estimated using % cover. Percent cover was visually estimated as the total % cover for all colonies of a given species on a side of a plate.

Organisms >0.25 mm in length associated with the flocculent material in each plate's container were identified and enumerated. Organisms found in the flocculent material were either motile organisms (unattached) or organisms that may have been dislodged from the plate surfaces during transport. Taxa richness and abundances were recorded for organisms in the flocculent material. A reference collection of 46 unique taxa from the settlement plates was preserved in 95% ethanol and is now maintained in the Marine Invertebrate Collection of the Beaty Biodiversity Museum, University of British Columbia, Vancouver, Canada.

Statistical analysis

Univariate measures of biodiversity (taxa richness and Shannon's diversity) on the plates were compared between the relative height above the benthos (lower branch versus upper branch, $n = 4$ plates per tree for a total of eight plates) and plate material (ceramic clay or frosted glass, $n = 4$ plates per tree for a total of eight plates) using a linear mixed effects model with tree as a random factor. Tree was included as a random factor to account for any effects due to tree placement and account for the nested structure of our study design. We did not examine the interaction between plate material and the relative height off the bottom, as this was not relevant to our hypotheses. The significance of all variables (fixed and random) was assessed using the lmerTest package in R version 3.6.1 (Kuznetsova *et al.* 2017; R Core Team 2019). All taxa associated with a single plate were pooled regardless of the side (i.e., top, bottom, or flocculent) on which they occurred. Diversity was analyzed separately for solitary and colonial organisms due to differences in how their abundance was recorded. Overall community structure was compared for all organism types using redundancy analysis (RDA) with presence-absence data. Separate RDAs were completed for both solitary and colonial animals using abundance data. For all RDA analyses the community data were transformed with a Hellinger transformation to meet the assumptions of the analysis. All RDAs included height above benthos, plate material, and tree as predictor variables. Overall RDA significance and the significance of individual axes were evaluated using analysis of variance. Taxa were con-

sidered associated with an axis if their goodness-of-fit score was 0.5 or higher. All analyses were conducted in R (version 3.6.1; R Core Team 2019).

Life history information and settlement timing

We assumed that juvenile taxa had settled on the plates relatively recently, within the previous two months. A list was generated of all taxa that were both identified to at least the genus level and had juveniles present on the plates. For these species we searched the literature for information regarding when spawning and/or larval settlement are known to occur. We also searched for information regarding larval and juvenile duration. The search was first restricted to reports from the northeast Pacific and then expanded to a global search. For species where information was found, we compared the published information with our findings.

Results

Water temperature differed significantly between the settlement trees during the period from March to August 2017 (paired *t*-test, $t_{15102} = 153.91$, $P < 0.0001$): tree 1 was in slightly warmer conditions (mean 9.15°C, range 8.25–10.96°C) compared to tree 2 (mean 9.06°C, range 8.17–10.76°C). Overall temperature range recorded in this study was 8.02–10.96°C.

Qualitative description of the invertebrate community

Overall, 70 taxa from 10 phyla were observed on the settlement plates ($n = 16$, including the top, bottom, and flocculent material for all plates). Most taxa (58, or 82.9%) were found on fewer than 50% of the plates and 28 species (40%) were found on a single plate. Three species were found on all 16 plates: *Alcyonidium* cf. *polyoum* (no common name, Bryozoa), Irregular Calcareous Tubeworm (*Crucigera irregularis*, Annelida), and Western Calcareous Tubeworm (*Pseudochitinopoma occidentalis*, Annelida). A full list of taxa identified on the plates can be found in Table S1. Annelids were by far the most taxa-rich phylum on our plates, with 23 taxa observed, followed by Cnidaria with 12 taxa observed, then by Bryozoa and Mollusca with 10 taxa each. A single taxon was observed for three phyla: Nemertea, Platyhelminthes, and Porifera. Despite having a single taxon representative, both Nemertea and Porifera were found on multiple plates (two and seven plates, respectively). Fewer taxa were observed on the tops of plates (33) than either in the flocculent material (47) or on the bottom side (49) of the plates. When only considering taxa that were observed more than once (i.e., multiple individuals or distinct colonies were seen) several taxa were found to occur on a single side of the plate. There were four taxa, each from a different phylum, that occurred only on the bottom sides of plates. These were *Stomatopora* sp. (Bryozoa), Tiny White Tunicate (*Bathypera feminalba*, Chordata [Tunicata]), *Epiactis* sp. (Cnidaria) and Doridacea indet. (Mollusca). A single taxon from Arthropoda, Balanomorpha indet., was found to only occur on the tops of the plates. Eleven taxa from four phyla (Annelida, Cnidaria, Mollusca, and Nemertea) were found only in the flocculent material (marked with a star in Table S1). All taxa found only in the flocculent material are mobile species. Regardless of the taxonomic level of organization examined, the bottom sides of plates were the most taxa-rich (Figure S1). Contrastingly, the flocculent material was consistently more diverse when considering solitary organisms (Figure S2) while there was no difference between plate sides in the diversity of colonial organisms (Figure S3; no colonial organisms were recorded in the flocculent material).

Effects of substrate and relative height above the benthos on invertebrate community composition and structure

Taxa richness on individual plates ranged from 11 to 25 (17.69 ± 4.00, mean ± SD). There was no difference in species richness attributable to the relative height off the benthos ($F_{1,12} = 0.16$, $P = 0.70$), the plate material ($F_{1,12} = 0.07$, $P = 0.79$), or the tree the plate was attached to ($\chi^2_1 = 0.54$, $P = 0.46$). Similarly, the diversity of both solitary and colonial organisms were not influenced by relative height off the benthos (solitary: $F_{1,12} = 0.52$, $P = 0.48$; colonial: $F_{1,12} = 0.12$, $P = 0.73$), plate material (solitary: $F_{1,12} = 1.79$, $P = 0.21$; colonial: $F_{1,12} = 3.62$, $P = 0.08$), or the tree to which the plate was attached (solitary: $\chi^2_1 = 2.19$, $P = 0.14$; colonial: $\chi^2_1 = 2.43$, $P = 0.12$). When the entire community was examined as a whole using presence-absence data and relative height off the benthos, plate material, and the tree the plate was attached to as explanatory variables, the RDA had an R^2_{adj} of 0.14 and one significant axis ($F_{1,12} = 3.41$, $P = 0.001$). The first and only significant axis separated the communities occurring on the two trees (Figure 3a). The barnacle Balanomorpha indet., the nudibranch Aeolidioidea indet., and the hydrozoan *Clytia hemisphaerica* were strongly associated with tree 2. When solitary taxa were analyzed separately, the same predictor variables resulted in an R^2_{adj} of 0.09 and one significant axis ($F_{1,12} = 2.53$, $P = 0.02$). The significant axis again corresponded with the tree to which the plates were attached (Figure 3b) and the barnacle Balanomorpha indet. and the nudibranch Aeolidioidea indet. were associated with tree 2. For colonial organisms, the RDA had an R^2_{adj} of 0.39 and a single significant axis ($F_{1,12} = 11.25$, $P = 0.002$), which again corresponded with the tree to which the plates were attached (Figure 3c). The hydrozoan *C. hemisphaerica* was associated with

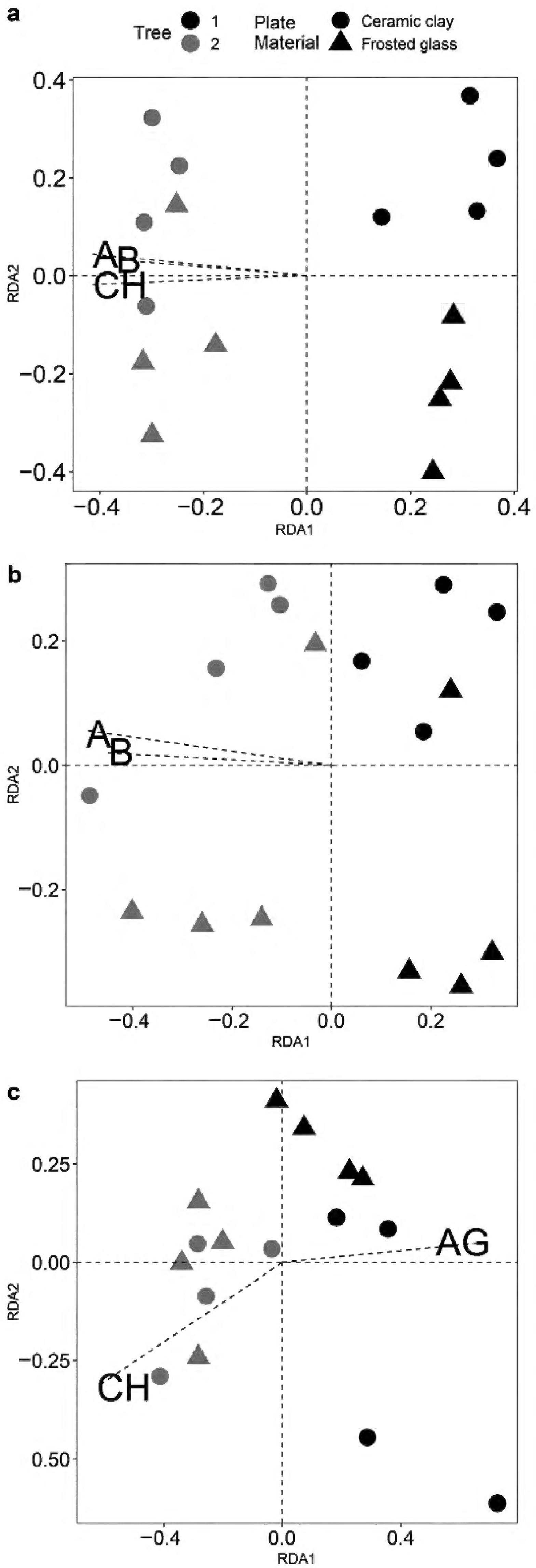


FIGURE 3. Biplot of the three redundancy analyses conducted using a. presence-absence data from the entire community, b. abundance data for solitary, and c. colonial organisms on the settlement plates. Species displayed were strongly associated with one or both of the axes displayed (goodness-of-fit of at least 0.50). There are significant differences between the communities found on the two trees. Plate material did not significantly influence community structure. The taxa names are abbreviated on the figure panels so that A = Aeolidioidea indet. (nudibranch), AG = *Amathia gracilis* (Bryozoan), B = Balanomorpha indet. (barnacle), and CH = *Clytia hemisphaerica* (hydrozoan).

tree 2 while the bryozoan *Amathia gracilis* was associated with tree 1.

Settlement timing

Juveniles of 17 taxa identifiable at the species or genus level were found on the plates at the time of collection (April 2018; Table 1). Of these, we were able to find information regarding spawn timing or larval settlement periods in the literature (for either the species we observed or members of the same genus) for 15 taxa. In most cases the information regarding reproductive timing was not based on studies from the northeastern Pacific. Regardless, the reported spawning or larval settlement timing generally agreed with our findings (Table 1). In four cases, *Paleanotus bellis*, *Pododesmus* sp., *Prionospio* (*Minuspio*) *multibranchiata*, and *Prionospio* (*Minuspio*) sp., our observation of juveniles on the plates in April does not correspond to spawning seasons reported in the literature. In all cases we observed juveniles of these species earlier than reported spawning periods. For *P. bellis* we found reports of spawning occurring between May and November with juvenile settlement occurring approximately three weeks later (Rasmussen 1956; Bhaud *et al.* 1987; Table 1), but we recorded juveniles in April. Similarly, for *Pododesmus* sp. our findings suggest spawning occurred earlier than has been previously reported, as Drozdov *et al.* (2009) reported spawning occurring in the Sea of Japan in May and then again from August to October. We did not find any reports on larval duration for this genus. In Atlantic Canada members of the *Prionospio* genus were found spawning between May and August (Lacalli 1981). It should be noted that *Prionospio patagonica* larvae were found in October, November, and March in Chile (Radashevsky *et al.* 2006), timing that corresponds seasonally to the appearance of juveniles on our plates in April, because Chile is in the southern hemisphere. In two cases, *Lanassa venusta venusta* and *Proclea* sp., we were unable to find any reports of spawn timing in the literature for species more closely related than the family level (i.e., in a different genus within the same family). For these two species there are reports of reproductive timing

TABLE 1. All taxa identifiable to the genus or species level that were present in their juvenile form when the settlement plates were collected in April 2018, with corresponding information regarding the location and timing of spawning or larval settlement available in the published literature. Common names are provided if they exist. Bolded species are those where our findings do not correspond with the published literature. In all cases we observed juveniles earlier than had previously been reported. Underlined species are those for which we could not identify any previously published information regarding the timing of spawning or larval settlement. Finally, records marked with an asterisk are from studies located in the southern hemisphere. The abbreviations NE stands for northeast, NW for northwest, SE for southeast, and SW for southwest.

Phylum / Class / Order / Family / Genus & species	Spawn timing	Larval settlement	Larval Duration	Location(s) of study	Comments	Citation(s)
Annelida						
Polychaeta						
Phyllodocida						
Chrysopetalidae						
Paleanotus bellis	May–Nov			North Sea		Rasmussen (1956)
			>3 wk	NE Atlantic		Cazaux 1968 as reported in Bhaud *et al.* (1987)
Polynoidae						
Harmothoe sp.	Dec–May			NE Atlantic		Daly (1972)
		All months		NE Pacific	Planktonic larvae present throughout the year with highest densities in February and March—studies done on *Harmothoe imbricata*	Blake (1975)
Syllidae						
Proceraea sp.		Dec–Aug		North Sea		Rasmussen (1973)
				NW Pacific		Britayev and San Martin (2001)
Sabellida						
Serpulidae						
Crucigera irregularis Irregular Calcareous Tubeworm	Mar–May			NE Pacific		Strathmann (1987)
Pseudochitinopoma occidentalis Western Calcareous Tubeworm		All months		NE Pacific	Reproductively active adults collected throughout the year	Hess (1993)
Spionida						
Spionidae						
Prionospio* (*Minuspio*) *multibranchiata		May–Aug		NW Atlantic	Report from a member of the same genus from Atlantic Canada	Lacalli (1981)
		Oct, Nov, Mar*		SE Pacific	Planktonic larvae of *Prionospio patagonica* reported in October, November, and March in Chile	Radashevsky *et al.* (2006)

TABLE 1. *Continued.*

Phylum / Class / Order / Family / Genus & species	Spawn timing	Larval settlement	Larval Duration	Location(s) of study	Comments	Citation(s)
***Prionospio (Minuspio)* sp.**		May–Aug		NW Atlantic	Report from a member of the same genus from Atlantic Canada	Lacalli (1981)
		Oct, Nov, Mar*		SE Pacific	Planktonic larvae of *Prionospio patagonica* reported in October, November, and March in Chile	Radashevsky *et al.* (2006)
Terebellida						
Terebellidae						
Lanassa venusta venusta					No reports of spawn timing in the literature	
Neoamphitrite sp.	May–July			NE Pacific		McHugh (1993)
Proclea sp.					No reports of spawn timing in the literature	
Chordata (Tunicata)						
Ascidiacea						
Phlebobranchia						
Corellidae						
Corella willmeriana Transparent Tunicate	All months	All months		NE Pacific		Lambert (1968)
Stolidobranchia						
Pyuridae						
Bathypera feminalba Tiny White Tunicate	Feb–Apr			NE Pacific	Species described from Saanich Inlet, BC	Young and Vazquez (1995)
Cnidaria						
Anthozoa						
Actiniaria						
Actiniidae						
Epiactis sp.	Jun, Oct			NE Pacific	Observations of spawning in California	Dunn (1975)
	Summer months*			Weddell Sea	inferred from samples of gonads in Weddell sea	Rodríguez *et al.* (2013)

TABLE 1. *Continued.*

Phylum / Class / Order / Family / Genus & species	Spawn timing	Larval settlement	Larval Duration	Location(s) of study	Comments	Citation(s)
Mollusca						
Bivalvia						
Adapedonta						
Hiatellidae						
Hiatella arctica Arctic Hiatella	Dec–Feb, May*			SW Pacific		Booth (1983)
	Jun–Sep	Jun–Nov		Barents Sea	Also references Kuafman (1977) as a report of spawn timing. We could not confirm this report as it is only available in Russian	Flyachinskaya and Lesin (2006)
	All months			NE Atlantic	In a population at 12 fathoms (~22 m) females with mature ova were found throughout the year	Hunter (1949)
Mytilida						
Mytilidae						
Mytilus sp.	All months			NE Pacific	Recruitment lowest in Jan-March	Connolly *et al.* (2001)
Pectinida						
Anomiidae						
***Pododesmus* sp.**	May, Aug–Oct			NW Pacific	Report from Sea of Japan	Drozdov *et al.* (2009)
Gastropoda						
Nudibranchia						
Dendronotidae						
Dendronotus sp.	Mar–Oct			Several	Several species from the Arctic, Barents Sea, and the NW Pacific	Ekimova *et al.* (2015)
	Mar–Oct		Short term		No clear definition of short-term but appears to be ~50 days from egg-larval development	Todd and Doyle (1981)

for closely related genera. However, our search was restricted to members of the same genus and therefore we did not include this information in Table 1. For the 15 species where we could find reports of the timing of reproduction and/or larval settlement, we were unable to find reports from the northeast Pacific for seven species. Therefore, our contribution represents the first clues to larval settlement timing in the northeast Pacific for nine species.

Non-indigenous species

None of the organisms identified to species in our study are known to be non-indigenous in BC. We recorded taxonomic relatives of non-indigenous species in BC with similar life histories (e.g., *Eusyllis blomstrandi* and *Eusyllis habei* are members of the same genus as *Eusyllis japonica*, a non-indigenous species in BC; Lu *et al.* 2007). It should be noted that *E. blomstrandi* may be part of a cryptic species complex in the northeastern Pacific (Kudenov *et al.* 1995).

Discussion

An important step in the processes of ensuring effective ecosystem-level conservation is building a thorough understanding of the systems we are attempting to protect. Sponge reefs are a high conservation priority because of their global rarity, slow growth and low recovery potential, and the biodiversity they support (Cook *et al.* 2008; Chu and Leys 2010; Kahn *et al.* 2015, 2016; Dunham *et al.* 2018). Previous work using remote video surveys has provided a thorough description of the larger fauna occurring on the reefs, yet a gap remained in our understanding of small taxa not detectable using remote methods. Here we present the first report of invertebrate settlement on a sponge reef in the Salish Sea and increase our understanding of biodiversity on sponge reefs.

There have been three previous studies on small macroinvertebrate fauna on sponge reefs in BC. However, all of these studies have occurred on the reefs in Hecate Strait (over 600 km to the northwest) and have studied animals found in cores or settled on sponges collected from the reef. Krautter *et al.* (2001) collected cores from the reefs in Hecate Strait and described a macroinvertebrate faunal community dominated by polychaetes and bryozoans, consistent with what we found in Howe Sound. Cook (2005) described the polychaete community on sponge reefs from cores taken within and around the Hecate Strait sponge reefs. They found 105 species of polychaetes from 27 families. We identified 22 polychaetes from nine families (Table S1). Interestingly we did not find any species reported in Cook (2005) and only two genera and four families were found in both studies. The Hecate Strait reefs and the reef in our study are separated by over 600 km and there is over a 100 m difference in the depth, those in Howe Sound being shallower. Therefore, it may be unsurprising that the taxa found in the two studies overlapped so little. Cook (2005) found a statistically significant difference in the polychaete communities on sponge reefs when compared to non-reef habitat immediately adjacent to the reefs. In the future it may be interesting to repeat a study similar to ours but with settlement plate trees located at similar depth in the off-reef habitat.

In a recent study, Guillas *et al.* (2019) looked at the macrofauna settled on *F. occa* individuals collected from a Hecate Strait reef. Despite the fact that their study and ours had only one species in common (Arctic Hiatella, *Hiatella arctica*) the overall community structure was similar with a community composed largely of sponges, bryozoans, molluscs, and polychaetes. However, our study documented two new phyla occurring on sponge reefs (Nemertea and Platyhelminthes) and expanded our knowledge of the settlement timing of invertebrates in this system. While our study failed to document any reef-building sponge settlement, Guillas *et al.* (2019), who collected reef-building sponges with both live and dead portions, found many small reef-building sponges potentially representing many settlement pulses over the past year. This is consistent with observations made by Kahn *et al.* (2016), who observed evidence of multiple reproductive events within a year on the Galiano Ridge sponge reef in the Salish Sea. While it is still unclear what environmental cues lead to spawning in reef-building glass sponges, it is likely, given other studies that report evidence of multiple spawning events within a calendar year, that reef-building sponges spawned while our settlement plates were deployed, but larvae did not recruit to the plates.

We did not find any difference in taxa richness, diversity, or community structure associated with the relative height above the benthos. In other words, height above benthos did not appear to structure the community on our settlement plates. This may have been for several reasons. First, the two trees were pushed into the substrate to different depths so that the branches were at 0.5 (tree 1), 0.65 (tree 2), 0.74 (tree 1), and 0.89 m (tree 2) above the benthos. If the data are reanalyzed so that actual height above benthos, rather than relative height above benthos, is included as a predictor variable the conclusions are still the same. A second reason is that a 0.24 m difference in height between the two branches is not large, particularly considering that sponges on BC's sponge reefs can often grow to be over 1 m tall (Conway *et al.* 2005). However, in other systems, such as seagrass beds, similar height differences have been found to influence survival, and therefore community structure,

of invertebrates (Pohle *et al.* 1991). Plate material similarly had no impact on taxa richness, diversity, or community structure. It is possible that both plate materials presented too similar a surface to influence community structure.

Although we did not test for it statistically, we did find that the side of the settlement plate was an important factor influencing taxa richness and diversity. Many marine invertebrates have a pelagic portion of their larval life history during which they are photosensitive, meaning exposure to light influences their behaviour (Thorson 1964). The vast majority of photosensitive larvae become photonegative, or move away from light, as they begin to settle out of the water column and into the benthic system (Thorson 1964). This behaviour often results in larvae settling onto the undersides of available surfaces as these are the surfaces with the lowest light levels (Thorson 1964), which is consistent with our findings. However, light levels are consistently low at our study site and further research would be necessary to determine if this behaviour is the cause of the patterns we observed. The high richness and diversity of taxa found in the flocculent material is also not surprising; these taxa were overwhelmingly motile. Other settlement plate studies, with sampling protocols that allowed for the capture and enumeration of motile taxa, have similarly reported high diversity in this group (Gartner 2010). Perhaps more surprising was the consistent difference in community between the two trees. One of the trees (tree 2) was toppled over at some point in the last three months of our study, it is possible that this led to the differences we observed as there was a significant difference in the total abundance of solitary taxa between the two trees ($t_{12.51} = -2.71$, $P = 0.02$). Additionally, we did observe a small, but statistically significant difference in the water temperatures recorded at each tree in the beginning of the study. While it is unlikely that this small difference in temperature would drive the differences in diversity, it may be indicative of an environmental gradient present within the sponge reef that relates to water movement and sedimentation and thus, likely, larval dispersal within the sponge reef. It is also possible that the difference in surrounding reef-building sponge abundance affected local fine-scale currents and influenced the species settling on each tree. Further study is warranted to investigate environmental gradients and the importance of local fine-scale current patterns within sponge reefs and how these relate to larval settlement and biodiversity patterns.

This is the first published settlement plate study at these depths in BC (31.7–33.5 m). Consequently, the species found on our plates largely differed from those in other, shallower, settlement plate studies in BC, but the overall community structure observed was similar with polychaetes, hydroids, and bryozoans being prevalent (Greene and Schoener 1982; Greene *et al.* 1983; Gartner 2010). One species we observed, *L. v. venusta* (phylum Annelida), is reported to be commensal with pagurids (hermit crabs; Hoberg *et al.* 1982), which have been observed on sponge reefs in the Salish Sea (Dunham *et al.* 2018). Interestingly, we did not observe any plumose anemone (*Metridium*) species settling on the plates despite the fact that they are a common member of settlement plate communities in BC (Greene and Schoener 1982; Greene *et al.* 1983; Gartner 2010) and are commonly observed around sponge reefs in the area (Dunham *et al.* 2018). The presence of predators can significantly influence the development of fouling communities (Nydam and Stachowicz 2007). While the majority of the species we observed were filter-feeders, we did collect several predatory species including a number of polychaetes, a nudibranch, and some parasitic species. For example, members of the genus *Proceraea* (phylum Annelida) have been reported as predators and parasites of bryozoans, sponges, ascidians, echinoderms, cnidarians, and decapods (Martín and Britayev 1998). Consequently, the presence of predatory polychaetes and nudibranchs on our plates may have prevented us from detecting the settlement of some common members of the invertebrate community. However, it should be noted that there were records of unidentified Actiniaria and Anthozoa juveniles from four plates. It is possible that these may have been *Metridium* juveniles. Future work is needed to fully unravel processes determining macroinvertebrate community development within sponge reefs.

We found juveniles identifiable to at least the genus level from four phyla present on our settlement plates (Annelida, Chordata [Tunicata], Cnidaria, and Mollusca; Table 1). Of the 17 unique taxa that we observed as juveniles we could find records of the timing of spawning and/or larval settlement for 15. Of these 15 taxa, eight had either spawn or larval settlement times reported in studies in the northeast Pacific and only one species had been studied in BC. Our observations of juveniles corresponded with the published timing of spawning or larval settlement for all taxa in studies conducted in the northeast Pacific. To the best of our knowledge our study is the first to elucidate potential spawn timing in *L. v. venusta* and a *Proclea* species. Members of this family are reported to spawn anytime throughout the year and display a wide range of life history strategies (McHugh 1993). Despite the wide variation in reproductive strategies in this family, all species seem to have a relatively short planktonic larval duration period (0–7.5 days; McHugh 1993 and references therein). Consequently, we can infer that spawning likely occurred in these

species in the weeks leading up to plate collection. Overall, over 51% of the individual organisms we observed, across all plates and taxa, were juveniles. The high number of juveniles on our settlement plates at the time of collection corresponds well with the hypothesis that many invertebrates in coastal BC waters spawn in the spring (Gartner 2010).

Although we did not have any reef-building sponges recruit to our settlement plates, continued settlement plate deployments focussed on testing different settlement materials and placement within the reefs could help fill important knowledge gaps on the factors influencing reef-building sponge recruitment. Additionally, continued settlement plate deployment could serve as an important monitoring tool for early detection of aquatic invasive species. Overall, our study helps to improve our understanding of biodiversity on sponge reefs.

Author Contributions

Conceptualization: S.K.A., S.B., A.D., G.D., and L.M.; Methodology: S.K.A., S.B., A.D., G.D., and L.M.; Investigation: S.B., G.D., and L.M.; Formal Analysis: S.K.A.; Writing – Original Draft: S.K.A.; Writing – Review & Editing: S.K.A., S.B., A.D., G.D., and L.M.; Funding Acquisition: A.D.

Acknowledgements

We would like to thank the Marine Life Sanctuaries Society of British Columbia (BC) and the Underwater Council of BC divers who volunteered their time for this project: Team Photographers: Deirdre McCracken, Diane Reid, Chris Straub, and Adam Taylor; Installation and retrieval divers: Meagen Abele, Brendan Andresen, Fabiola Ruiz Aguilar, Philippe Beaudry, Bobby Chan, Scott Dowd, Marley Heron, Rahim Kaba, Cassandra Konecny, Viviana Lee, Lauren Liggan, Scott Meixner, Amy Morgan-Young, Tanya Prinzing, Bartek (Bart) Radziej, and Joshua Teerling. The Department of Fisheries and Oceans' National Conservation Plan contributed funding to this project.

Literature Cited

Bhaud, M., C. Cazaux, C. Russell, and M. Lefevre. 1987. Description and identification of polychaete larvae: their implications in current biological problems. Oceanis 13: 595–753

Blake, J.A. 1975. The larval development of polychaeta from the northern California Coast. III eighteen species of errantia. Ophelia 14: 23–84. https://doi.org/10.1080/00785236.1975.10421969

Booth, J.D. 1983. Studies on twelve common bivalve larvae, with notes on bivalve spawning seasons in New Zealand. New Zealand Journal of Marine and Freshwater Research 17: 231–265. https://doi.org/10.1080/00288330.1983.9516001

Britayev, T.A., and G.L.A. San Martin. 2001. Description and life-history traits of a new species of *Proceraea* with larvae infecting *Abietinaria turgida* (Polychaeta, Syllidae & Hydrozoa, Sertulariidae). Ophelia 54: 105–113. https://doi.org/10.1080/00785236.2001.10409458

Chu, J., and S.P. Leys. 2010. High resolution mapping of community structure in three glass sponge reefs (Porifera, Hexactinellida). Marine Ecology Progress Series 417: 97–113. https://doi.org/10.3354/meps08794

Chu, J.W., M. Maldonado, G. Yahel, and S.P. Leys. 2011. Glass sponge reefs as a silicon sink. Marine Ecology Progress Series 441: 1–14. https://doi.org/10.3354/meps09381

Clayton, L., and G. Dennison. 2017. Inexpensive video drop-camera for surveying sensitive benthic habitats: applications from glass sponge (Hexactinellida) reefs in Howe Sound, British Columbia. Canadian Field-Naturalist 131: 46–54. https://doi.org/10.22621/cfn.v131i1.1783

Connolly, S.R., B.A. Menge, and J. Roughgarden. 2001. A latitudinal gradient in recruitment of intertidal invertebrates in the northeast Pacific Ocean. Ecology 82: 1799–1813. https://doi.org/10.2307/2680048

Conway, K., J. Barrie, W. Austin, and J. Luternauer. 1991. Holocene sponge bioherms on the western Canadian continental shelf. Continental Shelf Research 11: 771–790. https://doi.org/10.1016/0278-4343(91)90079-L

Conway, K.W., J.V. Barrie, and M. Krautter. 2005. Geomorphology of unique reefs on the western Canadian shelf: sponge reefs mapped by multibeam bathymetry. Geo-Marine Letters 25: 205–213. https://doi.org/10.1007/s00367-004-0204-z

Cook, S.E. 2005. Ecology of the hexactinellid sponge reefs on the western Canadian continental shelf. M.Sc. thesis, University of Victoria, Victoria, British Columbia, Canada.

Cook, S.E., K.W. Conway, and B. Burd. 2008. Status of the glass sponge reefs in the Georgia Basin. Marine Environmental Research 66: S80–S86. https://doi.org/10.1016/j.marenvres.2008.09.002

Daly, J.M. 1972. The maturation and breeding biology of *Harmothoë imbricata* (Polychaeta: Polynoidae). Marine Biology 12: 53–66. https://doi.org/10.1007/bf00347429

DFO (Fisheries and Oceans Canada). 2015. Fishery Notice FN0415. Accessed 10 January 2019. http://www-ops2.pac.dfo-mpo.gc.ca/fns-sap/index-eng.cfm?pg=view_notice&DOC_ID=183964&ID=all.

DFO (Fisheries and Oceans Canada). 2018. Glass Sponge aggregations in Howe Sound: locations, reef status, and ecological significance assessment. DFO Canadian Science Advise Secretariat Science Response 2018/032. Fisheries and Oceans Canada, Pacific Region, Canada.

DFO (Fisheries and Oceans Canada). 2019. Fishery Notice FN0205. Accessed 1 May 2019. https://www-ops2.pac.dfo-mpo.gc.ca/fns-sap/index-eng.cfm?pg=view_notice&DOC_ID=219517&ID=all.

Drozdov, A.L., S.N. Sharina, and S.A. Tyurin. 2009. Sperm ultrastructure in representatives of six bivalve families from Peter the Great Bay, Sea of Japan. Russian Journal of Marine Biology 35: 236–241. https://doi.org/10.1134/s1063074009030079

**Dunham, A., S.K. Archer, S.C. Davies, L.A. Burke, J.

Mossman, J.R. Pegg, and E. Archer. 2018. Assessing condition and ecological role of deep-water biogenic habitats: glass sponge reefs in the Salish Sea. Marine Environmental Research 141: 88–99. https://doi.org/10.1016/j.marenvres.2018.08.002

Dunham, A., J.R. Pegg, W. Carolsfeld, S.C. Davies, I. Murfitt, and J. Boutillier. 2015. Effects of submarine power transmission cables on a glass sponge reef and associated megafaunal community. Marine Environmental Research 107: 50–60. https://doi.org/10.1016/j.marenvres.2015.04.003

Dunn, D.F. 1975. Reproduction of the externally brooding sea anemone *Epiactis prolifera* Verrill, 1869. Biological Bulletin 148: 199–218. https://doi.org/10.2307/1540543

Ekimova, I., T. Korshunova, D. Schepetov, T. Neretina, N. Sanamyan, and A. Martynov. 2015. Integrative systematics of northern and Arctic nudibranchs of the genus *Dendronotus* (Mollusca, Gastropoda), with descriptions of three new species. Zoological Journal of the Linnean Society 173: 841–886. https://doi.org/10.1111/zoj.12214

Flyachinskaya, L.P., and P.A. Lesin. 2006. Using 3D reconstruction method in the investigations of Bivalvia larval development (by the example of *Hiatella arctica* L.). Proceedings of the Zoological Institute of the Russian Academy of Science 310: 45–50.

Gartner, H. 2010. Subtidal invertebrate fouling communities of the British Columbian coast. M.Sc. thesis, University of Victoria, Victoria, British Columbia, Canada.

Grant, N., E. Matveev, A.S. Kahn, S.K. Archer, A. Dunham, R.J. Bannister, D. Eerkes-Medrano, and S.P. Leys. 2019. Effect of suspended sediments on the pumping rates of three species of glass sponge in situ. Marine Ecology Progress Series 615: 79–100. https://doi.org/10.3354/meps12939

Greene, C.H., and A. Schoener. 1982. Succession on marine hard substrata: a fixed lottery. Oecologia 55: 289–297. https://doi.org/10.1007/bf00376914

Greene, C.H., A. Schoener, and E. Corets. 1983. Succession on marine hard substrata: the adaptive significance of solitary and colonial strategies in temperate fouling communities. Marine Ecology Progress Series 13: 121–129. https://doi.org/10.3354/meps013121

Guillas, K.C., A.S. Kahn, N. Grant, S.K. Archer, A. Dunham, and S.P. Leys. 2019. Settlement of juvenile glass sponges and other invertebrate cryptofauna on the Hecate Strait glass sponge reefs. Invertebrate Biology 138: e12266. https://doi.org/10.1111/ivb.12266

Hess, H.C. 1993. The evolution of parental care in brooding spirorbid polychaetes: the effect of scaling constraints. American Naturalist 141: 577–596. https://doi.org/10.1086/285492

Hoberg, M.K., S.G. McGee, and H.M. Feder. 1982. Polychaetes and amphipods as commensals with pagurids from the Alaska shelf. Ophelia 21: 167–179. https://doi.org/10.1080/00785326.1982.10426585

Hunter, W.R. 1949. The structure and behaviour of *Hiatella gallicana* (Lamarck) and *H. arctica* (L.), with special reference to the boring habit. Proceedings of the Royal Society of Edinburgh, Section B: Biology 63: 271–289. https://doi.org/10.1017/S0080455X00011930

Kahn, A.S., J.W.F. Chu, and S.P. Leys. 2018. Trophic ecology of glass sponge reefs in the Strait of Georgia, British Columbia. Scientific Reports 8: 756. https://doi.org/10.1038/s41598-017-19107-x

Kahn, A.S., L.J. Vehring, R.R. Brown, and S.P. Leys. 2016. Dynamic change, recruitment and resilience in reef-forming glass sponges. Journal of the Marine Biological Association of the United Kingdom 96: 429–436. https://doi.org/10.1017/S0025315415000466

Kahn, A.S., G. Yahel, J.W. Chu, V. Tunnicliffe, and S.P. Leys. 2015. Benthic grazing and carbon sequestration by deep-water glass sponge reefs. Limnology and Oceanography 60: 78–88. https://doi.org/10.1002/lno.10002

Krautter, M., K.W. Conway, J.V. Barrie, and M. Neuweiler. 2001. Discovery of a "Living Dinosaur": globally unique modern hexactinellid sponge reefs off British Columbia, Canada. Facies 44: 265–282. https://doi.org/10.1007/bf02668178

Kudenov, J., L. Harris, J. Blake, B. Hilbig, and P. Scott. 1995. Taxonomic atlas of the benthic fauna of the Santa Maria Basin and Western Santa Barbara channel. No. 5. Santa Barbara Museum of Natural History, Santa Barbara, California, USA.

Kuznetsova, A., P.B. Brockhoff, and R.H.B. Christensen. 2016. lmerTest: tests in linear mixed effects models. R package version 2.0-30. Accessed 8 April 2020. https://CRAN.R-project.org/package=lmerTest.

Lacalli, T. 1981. Annual spawning cycles and planktonic larvae of benthic invertebrates from Passamaquoddy Bay, New Brunswick. Canadian Journal of Zoology 59: 433–440. https://doi.org/10.1139/z81-063

Lambert, G. 1968. The general ecology and growth of a solitary ascidian, Corella willmeriana. Biological Bulletin 135: 296–307. https://doi.org/10.2307/1539783

Lu, L., C. Levings, and G. Piercey. 2007. Preliminary investigation on aquatic invasive species of marine and estuarine macrobenthic invertebrates on floating structures in five British Columbia harbours. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2814. Vancouver, British Columbia, Canada.

Maldonado, M., R. Aguilar, R.J. Bannister, J.J. Bell, K.W. Conway, P.K. Dayton, C. Díaz, J. Gutt, M. Kelly, E.L.R. Kenchington, S.P. Leys, S.A. Pomponi, H.T. Rapp, K. Rützler, O.S. Tendal, J. Vacelet, and C.M. Young. 2016. Sponge grounds as key marine habitats: a synthetic review of types, structure, functional roles, and conservation concerns. Pages 1–39 *in* Marine Animal Forests: The Ecology of Benthic Biodiversity Hotspots. *Edited by* S. Rossi, L. Bramanti, A. Gori, and C. Orejas Saco del Valle. Springer International Publishing, Cham, Switzerland. https://doi.org/10.1007/978-3-319-17001-5_24-1

Martín, D., and T.A. Britayev. 1998. Symbiotic polychaetes: review of known species. Oceanography and Marine Biology: an Annual Review 36: 217–340.

McHugh, D. 1993. A comparative study of reproduction and development in the polychaete family Terebellidae.

Biological Bulletin 185: 153–167. https://doi.org/10.2307/1541996

Nydam, M., and J.J. Stachowicz. 2007. Predator effects on fouling community development. Marine Ecology Progress Series 337: 93–101. https://doi.org/10.3354/meps337093

Pohle, D.G., V.M. Bricelj, and Z. García-Esquivel. 1991. The eelgrass canopy: an above-bottom refuge from benthic predators for juvenile bay scallops *Argopecten irradians*. Marine Ecology Progress Series 74: 47–59. https://doi.org/10.3354/meps074047

R Core Team. 2019. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Radashevsky, V.I., M. Díaz, and C. Bertrán. 2006. Morphology and biology of *Prionospio patagonica* (Annelida: Spionidae) from Chile. Journal of the Marine Biological Association of the United Kingdom 86: 61–69. https://doi.org/10.1017/S0025315406012860

Rasmussen, E. 1956. The reproduction and larval development of some polychaetes from Isefjord, with some faunistic notes. Biologiske Meddelelser udgivet af Det Kongelige Danske Videnskabernes Selskab 23: 1–90.

Rasmussen, E. 1973. Systematics and ecology of the Isefjord marine fauna (Denmark). Ophelia 11: 1–507. https://doi.org/10.1080/00785326.1973.10430115

Rodriguez, S.R., F.P. Ojeda, and N.C. Inestrosa. 1993. Settlement of benthic marine invertebrates. Marine Ecology Progress Series 97: 193–207. https://doi.org/10.3354/ meps097193

Rodríguez, E., C. Orejas, P.J. López-González, and J.M. Gili. 2013. Reproduction in the externally brooding sea anemone *Epiactis georgiana* in the Antarctic Peninsula and the Weddell Sea. Marine Biology 160: 67–80. https://doi.org/10.1007/s00227-012-2063-x

Stone, R.P., K.W. Conway, D. Csepp, and J. Barrie. 2014. The boundary reefs: glass sponge (Porifera: Hexactinellidae) reefs on the international border between Canada and the United States. NOAA Technical Memorandum NMFS-AFSC 264: 1–41.

Strathmann, M.F. 1987. Reproduction and Development of Marine Invertebrates of the Northern Pacific. University of Washington Press, Seattle, Washington, USA.

Thorson, G. 1964. Light as an ecological factor in the dispersal and settlement of larvae of marine bottom invertebrates. Ophelia 1: 167–208. https://doi.org/10.1080/00785326.1964.10416277

Todd, C.D., and R.W. Doyle. 1981. Reproductive strategies of marine benthic invertebrates: a settlement-timing hypothesis. Marine Ecology Progress Series 4: 5–8. https://doi.org/10.3354/meps004075

Young, C.M., and E. Vazquez. 1995. Morphology, larval development, and distribution of *Bathypera feminalba* n. sp. (Ascidiacea: Pyuridae), a deep-water ascidian from the fjords and sounds of British Columbia. Invertebrate Biology 114: 89–106. https://doi.org/10.2307/3226958

Received 10 June 2019
Accepted 28 February 2020

SUPPLEMENTARY MATERIALS:

TABLE S1. All taxa recorded on the settlement plates.

FIGURE S1. Mean taxa richness observed on a plate by taxonomic level and the side of the settlement plate ($n = 16$ per bar).

FIGURE S2. Mean taxa diversity for solitary organisms observed on a plate by taxonomic level and the side of the settlement plate ($n = 16$ per bar).

FIGURE S3. Mean taxa diversity for colonial organisms observed on a plate by taxonomic level and the side of the settlement plate ($n = 16$ per bar).

The Canadian Field-Naturalist

First record of *Crithidia expoeki* (Trypanosomatida: Trypanosomatidae) from native Canadian bumble bees (Hymenoptera: Apidae: *Bombus*)

Kirsten M. Palmier[1,2,*], **Amber D. Tripodi**[3], **Andrew D.S. Cameron**[1], **James P. Strange**[3,4], **and Cory S. Sheffield**[2]

[1]Department of Biology, University of Regina, 3737 Wascana Parkway, Regina, Saskatchewan S4S 0A2 Canada
[2]Royal Saskatchewan Museum, 2340 Albert Street, Regina, Saskatchewan S4P 2V7 Canada
[3]United States Department of Agriculture, Agricultural Research Service, Pollinating Insect Research Unit, 1410 N 800 East, Logan, Utah 84341 USA
[4]Current address: Department of Entomology, The Ohio State University, Columbus, Ohio 43210 USA
[*]Corresponding author: kir.palmier@gmail.com

Palmier, K.M., A.D. Tripodi, A.D.S. Cameron, J.P. Strange, and C.S. Sheffield. 2020. First record of *Crithidia expoeki* (Trypanosomatida: Trypanosomatidae) from native Canadian bumble bees (Hymenoptera: Apidae: *Bombus*). Canadian Field-Naturalist 134(1): 16–20. https://doi.org/10.22621/cfn.v134i1.2299

Abstract
Bumble bees (*Bombus* Latrielle: Apidae) are important pollinators; however, declines of several species have been documented worldwide. Although pathogens have been linked to some declines, the biology, distribution, and impacts of most pathogens are poorly understood. Here, we report the first record of a recently characterized protozoan pathogen, *Crithidia expoeki* Schmid-Hempel & Tognazzo (Trypanosomatida: Trypanosomatidae), from bumble bees in Canada. This provides further insight on its global distribution and importance as a threat to bumble bees in Canada.

Key words: *Crithidia*; bumble bees; pathogens; Canadian distribution

Introduction
Bumble bees (*Bombus* Latrielle: Apidae) are important pollinators in both agricultural and natural landscapes (Batra 1995; Frier *et al.* 2016; Gibbs *et al.* 2016), but, unfortunately, some native species are experiencing dramatic declines in population size, range, or both. In Canada, six bumble bee species have been assessed as species at risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Three of these belong to the subgenus *Bombus* Latrielle *sensu stricto*: Rusty-patched Bumble Bee (*Bombus affinis* Cresson; Endangered; COSEWIC 2010), Western Bumble Bee (*Bombus occidentalis* Greene; Threatened; COSEWIC 2014a), and Yellow-banded Bumble Bee (*Bombus terricola* Kirby; Special Concern; COSEWIC 2015). Two belong to the subgenus *Psithyrus* Lepeletier: Gypsy Cuckoo Bumble Bee (*Bombus bohemicus* (Seidl); Endangered; COSEWIC 2014b) and Suckley's Cuckoo Bumble Bee (*Bombus suckleyi* Greene; Threatened; COSEWIC 2019 *in press*). Both *Psithyrus* species that have been assessed by COSEWIC are nest parasites or cuckoos of the three members of the subgenus *Bombus* indicated above. The sixth species, American Bumble Bee (*Bombus pensylvanicus* (De Geer)), is not closely related to any of the others, but was also recently assessed (Special Concern; COSEWIC 2018). All these species have been assessed based on declines in population abundance, decreases of their former ranges, or both.

Previously, declines in bumble bee populations have been linked to pathogens and parasites (Colla and Packer 2008; Cameron *et al.* 2011; Graystock *et al.* 2013; Tripodi and Strange 2018), but our knowledge is still incomplete with respect to all of the organisms involved and their relative importance. This lack of detailed knowledge of presumed threats has important implications for conservation assessments, such as those of COSEWIC, especially when the causes of declines are not specifically known. Thus,

knowing the specific pathogens involved helps to determine the conservation status.

The Trypanosomatidae (Trypanosomatida) are a diverse group of flagellated protozoan parasites, and many species are of medical and agricultural importance (Dedet and Pratlong 2000; Podlipaev *et al.* 2004). For example, *Crithidia bombi* Lippa & Triggiani is a common, widespread parasite of bumble bees and was the first flagellated protozoan identified from their guts (Gorbunov 1987). Recently, molecular data helped differentiate a second species of *Crithidia*, *Crithidia expoeki* Schmid-Hempel & Tognazzo, from the closely related *Crithidia bombi* (Schmid-Hempel and Tognazzo 2010). Initially, Schmid-Hempel and Tognazzo (2010) found both species of *Crithidia* in Alaska (USA) and Switzerland, and subsequent surveillance has detected *C. expoeki* in the contiguous United States and Mexico (Gallot-Lavallée *et al.* 2016; Tripodi *et al.* 2018). *Crithidia expoeki* is expected to be as widespread as *C. bombi* (Tripodi *et al.* 2018), although additional data are needed to confirm the presence of this recently described pathogen and determine its distribution and host(s).

Crithidia infections in bumble bees have been reported at individual, colony, and population levels. *Crithidia* infections are typically chronic and rarely lead to mortality except under conditions of nutritional limitation (Brown *et al.* 2000; Conroy *et al.* 2016). Workers infected with *Crithidia* exhibit reduced foraging efficiency because of an impaired ability to learn the colour of rewarding flowers (Gegear *et al.* 2006), ultimately resulting in negative impacts on colony (Otterstatter *et al.* 2005) and plant reproductive success (Waser 1983). In spring, bumble bee queens infected with *Crithidia* are less fit than their uninfected counterparts, making them less able to establish colonies successfully; colonies started by infected queens yield fewer workers and reproducing individuals, which lowers the overall genetic variability of populations (Brown *et al.* 2003). When genetic variation within bumble bee populations decreases, it reduces the ability of colonies to overcome the pressures of parasitism (Liersch and Schmid-Hempel 1998) and likely other stressors (Zayed 2009).

Crithidia bombi and *C. expoeki* outbreaks can spread rapidly because these monoxenous (i.e., requiring one host) parasites do not require a vector for transmission between hosts (Maslov *et al.* 2013), unlike the many heteroxenous trypanosomatids that require two hosts and depend on an insect vector for transmission between them. *Crithidia* are transmitted horizontally within colonies via contaminated surfaces and food, whereas transmission between colonies occurs via flower sharing (Durrer and Schmid-Hempel 1994), although the pathogen can only survive outside a living host for short periods (Imhoof and Schmid-Hempel 1999).

Crithidia bombi and *C. expoeki* are microscopic and their appearance varies throughout their life cycles, making it difficult to distinguish between species morphologically. Historically, polymerase chain reaction (PCR) for detecting *Crithidia* in bumble bees did not distinguish below the genus level; thus, all positive results were assumed to be *C. bombi*, as no other taxa were recognized (Tripodi *et al.* 2018). The two species of *Crithidia* were distinguished by DNA sequencing (Schmid-Hempel and Tognazzo 2010). More recently, Tripodi *et al.* (2018) developed a two-step multiplex PCR protocol using species-specific primers that can distinguish *C. bombi* and *C. expoeki* in samples. This multiplex assay can also detect unexpected trypanosomatid relatives that can be identified through subsequent DNA sequencing.

Although *Crithidia* is distributed globally (Durrer and Schmid-Hempel 1995), it is unclear whether individual species follow specific geographic patterns. In the United States, *C. bombi* is more common than *C. expoeki*, but co-infections by both are more common than single *C. expoeki* infections (Tripodi *et al.* 2018). In southern Mexico, bumble bees were more commonly infected by an undescribed *Crithidia* species "*Crithidia mexicana*", followed by *C. expoeki*, with only rare cases of *C. bombi* (Gallot-Lavallée *et al.* 2016). Currently, "*C. mexicana*" has not been detected in North America north of Mexico (Tripodi *et al.* 2018), suggesting that trypanosomatid parasites of bumble bees may follow geographic patterns, although more species-specific studies are needed to interpret distribution patterns. Here, we present the first report of *C. expoeki* in Canada.

Methods

In July 2016, bumble bees were collected throughout Saskatchewan for a preliminary study to assess their pathogens. Bees were captured using aerial nets and stored individually in 1.5-mL Eppendorf tubes filled with 100% ethanol. The individual bees were frozen until they were ready to be processed. Each bee gut was dissected and screened for additional parasites or abnormalities in the haemocoel, before midgut, fat bodies, Malpighian tubes, and hind gut were removed; voucher specimens used in this study were placed in the invertebrate zoology collection at the Royal Saskatchewan Museum. Sterile techniques were used to prevent cross-contamination among the samples. DNA was extracted from the gut and fat body tissue using a modified protocol 6 from Sambrook and Russel (2001). Trypanosomatids were

screened using the two-step multiplex PCR developed by Tripodi *et al.* (2018), which detects and differentiates between *Crithidia* species.

Results

In a subsample of 30 bumble bees, collected from two sites in Saskatchewan (53.2517°N, 104.4757°W; 52.4952°N, 103.5213°W), 44% tested positive for *Crithidia* spp. Of those *Crithidia*-positive individuals, 58% tested positive for *C. bombi*, 25% for *C. expoeki*, and 8% for an uncharacterized typanosomatid (Table 1).The positive-testing individuals occurred in three bumble bee species: Tri-coloured Bumble Bee (*Bombus ternarius* Say), Yellow-banded Bumble Bee, and Half-black Bumble Bee (*Bombus vagans* Smith). One *B. vagans* tested positive for both *Crithidia* species; for three samples, we were unable to diagnose because of failed reactions (Table 1).

Discussion

Historically, *C. bombi* and *C. expoeki* were considered the same species; therefore, little is known about the more recently defined latter species, including its geographic distribution, host specificity, and the specific or differing effects it has on its hosts. Although these effects and host specificity are not considered here, our study does present the first confirmed detection of *C. expoeki* in Canada, which offers some new insight on its distribution. Recommendations for future studies screening for *Crithidia* should distinguish between species and screen for any possibly uncharacterized trypanosomatids. As several species of bumble bee are considered at risk in Canada, including the six assessed by COSEWIC, future screening for *C. expoeki* from recent (and historical) collections would provide valuable information about the importance of trypanosomatids in these declines.

The causes of declines in Canadian bumble bees are poorly understood, but likely include pesticides, competition with introduced/managed species, reductions in flowering plants and other land use practices, climate change, and pathogens (Cameron *et al.* 2011). There is still much to learn about the specific pathogens involved in addition to their mode of transfer and infection, cumulative effect when combined with other threats, and geographic distribution.

Author Contributions

Writing – Original Draft: K.M.P.; Writing – Review & Editing: A.D.S.C., A.D.T., C.S.S., J.P.S., and K.M.P.; Conceptualization: A.D.T. and J.P.S.; Data Curation: C.S.S. and K.M.P.; Funding Acquisition: A.D.S.C. and C.S.S.; Investigation: K.M.P.; Methodology: A.D.T. and J.P.S.; Resources: A.D.T, J.P.S., and K.M.P.; Validation: A.D.T. and J.P.S.; Visualization: K.M.P.

Acknowledgements

We gratefully acknowledge the Saskatchewan Ministry of Agriculture and the Canada–Saskatchewan Growing Forward 2 bi-lateral agreement, delivered by the Agriculture Council of Saskatchewan, for funding and support in this project.

Literature Cited

Batra, S.W.T. 1995. Bees and pollination in our changing environment. Apidologie 26: 361–370. https://doi.org/10.1051/apido:19950501

Brown, M.J.F., R. Loosli, and P. Schmid-Hempel. 2000. Condition-dependent expression of virulence in a trypanosome infecting bumblebees. Oikos 91: 421–427. https://doi.org/10.1034/j.1600-0706.2000.910302.x

Brown, M.J.F., R. Schmid-Hempel, and P. Schmid-Hempel. 2003. Strong context-dependent virulence in a host–parasite system: reconciling genetic evidence with theory. Journal of Animal Ecology 72: 994–1002. https://doi.org/10.1046/j.1365-2656.2003.00770.x

Cameron, S.A., J.D. Lozier, J.P. Strange, J.B. Koch, N. Cordes, L.F. Solter, and T.L. Griswold. 2011. Patterns of widespread decline in North American bumble bees. Proceedings of the National Academy of Sciences of the United States of America 108: 662–667. https://doi.org/10.1073/pnas.1014743108

Colla, S.R., and L. Packer. 2008. Evidence for decline in eastern North American bumblebees (Hymenoptera: Apidae), with special focus on *Bombus affinis* Cresson. Biodiversity and Conservation 17: 1379. https://doi.org/10.1007/s10531-008-9340-5

TABLE 1. *Bombus* species in Saskatchewan, Canada, that tested positive through a multiplex polymerase chain reaction for *Crithidia bombi*, *Crithidia expoeki*, or an uncharacterized trypanosomatid.

Bombus species	No. positive tests for a trypanosomatid			No. *Crithidia* co-infections	No. negatives for *Crithidia* spp.
	C. bombi	*C. expoeki*	Un-characterized		
Bombus ternarius (n = 13)	1	1	2	0	7
Bombus terricola (n = 7)	2	0	0	0	5
Bombus vagans (n = 10)	4	2	1	1	3

Note: Deviations from total sample sizes are a result of failure of the positive control in two specimens of *B. ternarius* and one of *B. vagans*.

Conroy, T.J., E.C. Palmer-Young, R.E. Irwin, and L.S. Adler. 2016. Food limitation affects parasite load and survival of *Bombus impatiens* (Hymenoptera: Apidae) infected with Crithidia (Trypanosomatida: Trypanosomatidae). Environmental Entomology 45: 1212–1219. https://doi.org/10.1093/ee/nvw099

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2010. COSEWIC assessment and status report on the Rusty-patched Bumble Bee, *Bombus affinis*, in Canada. COSEWIC, Ottawa, Ontario, Canada.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2014a. COSEWIC assessment and status report on the Western Bumble Bee, *Bombus occidentalis* subspecies (*Bombus occidentali occidentalis*) and the *mckayi* subspecies (*Bombus occidentalis mckayi*), in Canada. COSEWIC, Ottawa, Ontario, Canada.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2014b. COSEWIC assessment and status report on the Gypsy Cuckoo Bumble Bee, *Bombus bohemicus*, in Canada. COSEWIC, Ottawa, Ontario, Canada.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2015. COSEWIC assessment and status report on the Yellow-banded Bumble Bee, *Bombus terricola*, in Canada. COSEWIC, Ottawa, Ontario, Canada.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2018. COSEWIC assessment and status report on the American Bumble Bee, *Bombus pensylvanicus*, in Canada. COSEWIC, Ottawa, Ontario, Canada.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2019. *in press*. COSEWIC assessment and status report on Suckley's Cuckoo Bumble Bee, *Bombus suckleyi*, in Canada. COSEWIC, Ottawa, Ontario, Canada.

Dedet, J.P., and F. Pratlong. 2000. *Leishmania*, *Trypanosoma* and monoxenous trypanosomatids as emerging opportunistic agents. Journal of Eukaryotic Microbiology 47: 37–39. https://doi.org/10.1111/j.1550-7408.2000.tb00008.x

Durrer, S., and P. Schmid-Hempel. 1994. Shared use of flowers leads to horizontal pathogen transmission. Proceedings of the Royal Society B: Biological Sciences 258: 299–302. https://doi.org/10.1098/rspb.1994.0176

Durrer, S., and P. Schmid-Hempel. 1995. Parasites and the regional distribution of bumblebee species. Ecography 18: 114–122. https://doi.org/10.1111/j.1600-0587.1995.tb00331.x

Frier, S.D., C.M. Somers, and C.S. Sheffield. 2016. Comparing the performance of native and managed pollinators of Haskap (*Lonicera caerulea*: Caprifoliaceae), an emerging fruit crop. Agriculture, Ecosystems & Environment 219: 42–48. https://doi.org/10.1016/j.agee.2015.12.011

Gallot-Lavallée, M., R. Schmid-Hempel, R. Vandame, C.H. Vergara, and P. Schmid-Hempel. 2016. Large scale patterns of abundance and distribution of parasites in Mexican bumblebees. Journal of Invertebrate Pathology 133: 73–82. https://doi.org/10.1016/j.jip.2015.12.004

Gegear, R.J., M.C. Otterstatter, and J.D. Thomson. 2006. Bumble-bee foragers infected by a gut parasite have an impaired ability to utilize floral information. Proceedings of the Royal Society B: Biological Sciences 273: 1073–1078. https://doi.org/10.1098/rspb.2005.3423

Gibbs, J., E. Elle, K. Bobiwash, T. Haapalainen, and R. Isaacs. 2016. Contrasting pollinators and pollination in native and non-native regions of highbush blueberry production. PLoS ONE 11: 1–24. https://doi.org/10.1371/journal.pone.0158937

Gorbunov, P.S. 1987. Endoparasitic flagellates of the genus *Crithidia* (Trypanosomatidae, Zoomastigphora) from the alimentary canal of bumblebees. Zoologicheskii Zhurnal 66: 1775–1780.

Graystock, P., K. Yates, B. Darvill, D. Goulson, and W.O.H. Hughes. 2013. Emerging dangers: deadly effects of an emergent parasite in a new pollinator host. Journal of Invertebrate Pathology 114: 114–119. https://doi.org/10.1016/j.jip.2013.06.005

Imhoof, B., and P. Schmid-Hempel. 1999. Colony success of the bumble bee, *Bombus terrestris*, in relation to infections by two protozoan parasites, *Crithidia bombi* and *Nosema bombi*. Insectes Sociaux 46: 233–238. https://doi.org/10.1007/s000400050139

Liersch, S., and P. Schmid-Hempel. 1998. Genetic variation within social insect colonies reduces parasite load. Proceedings of the Royal Society B: Biological Sciences 265: 221–225. https://doi.org/10.1098/rspb.1998.0285

Maslov, D.A., J. Votýpka, V. Yurchenko, and J. Lukeš. 2013. Diversity and phylogeny of insect trypanosomatids: all that is hidden shall be revealed. Trends in Parasitology 29: 43–52. https://doi.org/10.1016/j.pt.2012.11.001

Otterstatter, M.C., R.J. Gegear, S.R. Colla, and J.D. Thomson. 2005. Effects of parasitic mites and protozoa on the flower constancy and foraging rate of bumble bees. Behavioral Ecology and Sociobiology 58: 383–389. https://doi.org/10.1007/s00265-005-0945-3

Podlipaev, S.A., N.R. Sturm, I. Fiala, O. Fernandes, S.J. Westenberger, M. Dollet, D.A. Campbell, and J. Lukeš. 2004. Diversity of insect trypanosomatids assessed from the spliced leader RNA and 5S rRNA genes and intergenic regions. Journal of Eukaryotic Microbiology 51: 283–290. https://doi.org/10.1111/j.1550-7408.2004.tb00568.x

Sambrook, J., and D.W. Russell. 2001. Molecular Cloning: a Laboratory Manual. Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York, USA.

Schmid-Hempel, R., and M. Tognazzo. 2010. Molecular divergence defines two distinct lineages of *Crithidia bombi* (Trypanosomatidae), parasites of bumblebees. Journal of Eukaryotic Microbiology 57: 337–345. https://doi.org/10.1111/j.1550-7408.2010.00480.x

Tripodi, A.D., and J.P. Strange. 2018. Rarely reported, widely distributed, and unexpectedly diverse: molecular characterization of mermithid nematodes (Nematoda: Mermithidae) infecting bumble bees (Hymenoptera: Apidae: *Bombus*) in the USA. Parasitology 145: 1558–1563. https://doi.org/10.1017/S0031182018000410

Tripodi, A.D., A.L. Szalanski, and J.P. Strange. 2018. Novel multiplex PCR reveals multiple trypanosomatid species infecting North American bumble bees (Hymenoptera: Apidae: *Bombus*). Journal of Invertebrate Pathology 153: 147–155. https://doi.org/10.1016/j.jip.2018.03.009

Waser, N.M. 1983. The adaptive nature of floral traits: ideas and evidence. Pages 241–285 *in* Pollination Biology. *Edited by* L.A. Real. Academic Press, Orlando, Florida, USA.

Zayed, A. 2009. Bee genetics and conservation. Apidologie 40: 237–262. https://doi.org/10.1051/apido/2009026

Received 4 July 2019
Accepted 28 February 2020

The Canadian Field-Naturalist

Diet of St. Lawrence Estuary Beluga (*Delphinapterus leucas*) in a changing ecosystem

Véronique Lesage[1,*], Stéphane Lair[2], Samuel Turgeon[1], and Pierre Béland[3]

[1]Maurice Lamontagne Institute, Fisheries and Oceans Canada, P.O. Box 1000, 850 Route de la Mer, Mont-Joli, Quebec G5H 3Z4 Canada
[2]Faculté de médecine vétérinaire, Université de Montréal, 3200 Rue Sicotte, St-Hyacinthe, Quebec J2S 2M2 Canada
[3]St. Lawrence National Institute of Ecotoxicology, 6207 Louis-Hébert, Montreal, Quebec H2G 2G6 Canada
*Corresponding author: veronique.lesage@dfo-mpo.gc.ca

Lesage, V., S. Lair, S. Turgeon, and P. Béland. 2020. Diet of St. Lawrence Estuary Beluga (*Delphinapterus leucas*) in a changing ecosystem. Canadian Field-Naturalist 134(1): 21–35. https://doi.org/10.22621/cfn.v134i1.2421

Abstract

Ecosystems and community structure fluctuate over time as a result of natural and anthropogenic factors that may affect prey availability and population dynamics. Most of what we know about St. Lawrence Estuary (SLE) Beluga (*Delphinapterus leucas*) diet comes from stomach contents collected 80 years ago mainly from a hunting site that Beluga no longer use. How reflective these data are of Beluga diet at other sites and at the current time is unknown. In the context of the recent population decline, general information of prey species alone may help identify useful conservation actions for potentially important prey or habitats. Here, we examined the diet of SLE Beluga using digestive tracts collected from carcasses recovered over the past 30 years, in the context of historical diet data and recent changes in the St. Lawrence ecosystem. We showed they have a varied diet composed of fish and invertebrates generally <30 cm in length, and that adult males and females differ in their summer diet in a way that is consistent with the sex segregation observed in this population. Our results also indicate that polychaete worms, squid, and cod are still among the most prevalent prey, and that species such as redfish (*Sebastes* spp.) might be important prey items. This study shows that Beluga diet has changed since the 1930s, and that prey from digestive tracts identified to species are valuable for making comparisons to the past, and for improving applications of molecular analyses, such as stable isotopes and fatty acids.

Key words: *Delphinapterus leucas*; foraging ecology; diet; Beluga; ecosystem change

Introduction

Ecosystems and community structure fluctuate over time as a result of a variety of natural and anthropogenic factors. These environmental changes may modify prey availability and affect predator population dynamics. Without contemporary information on diet composition and foraging ecology, predicting a population's response to human stressors and climate variability remains a challenge (Bowen 1997).

A small population of Beluga whale (*Delphinapterus leucas*) persists in the St. Lawrence Estuary (SLE), Canada (Figure 1), since the last glaciation (Harington 1977). Full protection from hunting since the late 1970s should have allowed this population to grow. Instead, the population has remained stable or may have increased slightly until the early 2000s but is in a steady decline at a rate of about 1% per year since then (Mosnier *et al.* 2015). This led to a change in conservation status from Threatened to Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2014), and under the Canadian *Species at Risk Act* (Canada Gazette 2016). Reasons for the lack of recovery and current decline may include contamination, disruption of critical activities by vessel traffic, and reduced access or availability of prey as a result of ecosystem change (DFO 2014). Understanding Beluga diet and foraging ecology may help identify dietary sources of toxic substances, and prey species and habitats most valuable to Beluga recovery.

Most of what we know about SLE Beluga diet comes from stomach contents collected 80 years ago mainly from a hunting site no longer used by SLE Beluga (Vladykov 1946). How reflective these data are of the current Beluga diet and at other sites is uncertain. Since the 1930s, the St. Lawrence marine ecosystem has seen an increase in abundance of potential competitors such as Gray Seal (*Halilchoerus grypus*) and Harp Seal (*Pagophilus groenlandicus*; Hammill *et al.* 2015, 2017), and the collapse of several com-

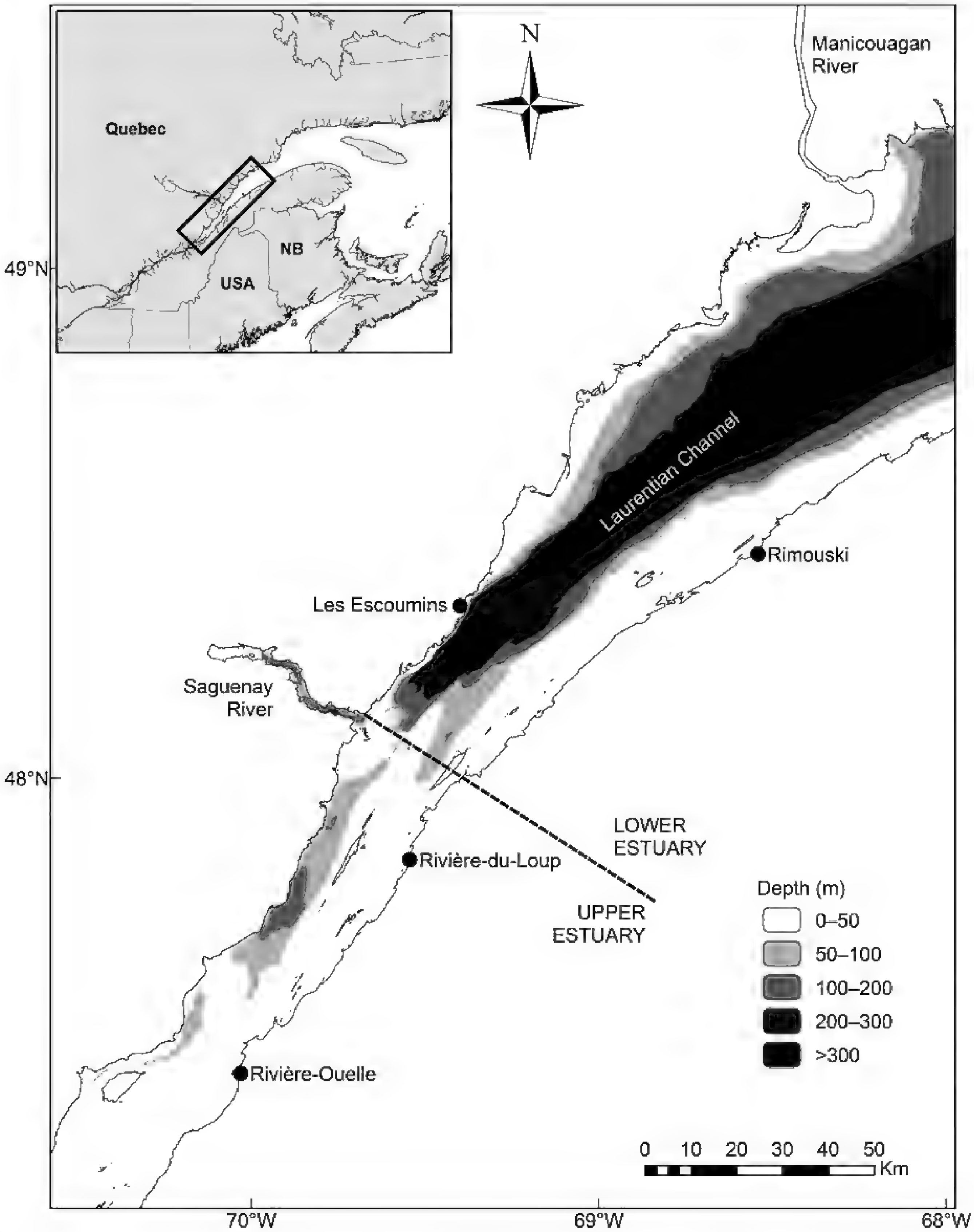


FIGURE 1. Study area, in the St. Lawrence Estuary, Canada. Upper estuary and lower estuary refer to sectors located west and east of the Saguenay River, respectively. The main hunting site in the Vladykov (1946) study was located on Manicouagan bank, right off Manicouagan River. In our study, Beluga (*Delphinapterus leucas*) were collected for stomach contents throughout the St. Lawrence Estuary.

mercially exploited demersal fish species, with a concurrent expansion of some crustacean and small pelagic fish stocks (Worm and Myers 2003; Savenkoff *et al.* 2007). Species such as Northern Shortfin Squid (*Illex illecebrosus*) and Atlantic (*Gadus morhua*) or Greenland (*Gadus ogac*) Cod, which were consumed regularly during the 1930s, are scarce in recent SLE scientific fisheries, raising questions about their availability to Beluga. American Eels (*Anguilla rostrata*), which were suspected to be an important source of PCBs and other persistent organic pollutants including Mirex in Beluga, collapsed in the SLE in the 1990s (Hickie *et al.* 2000; Cairns *et al.* 2014). Meanwhile, severely depleted fish populations such as redfish (*Sebastes* spp.) and Striped Bass (*Morone saxatilis*) are currently rebounding from low levels (COSEWIC 2012; Brassard *et al.* 2017; DFO 2017; Vanalderweireldt 2019).

Insights into SLE Beluga contemporary diet might be obtained from quantitative dietary mixing mod-

els that exploit molecular tracers such as stable isotopes or fatty acids (e.g., Iverson *et al.* 2004; Moore and Semmens 2008; Parnell *et al.* 2010). However, an important assumption of these models is that all potentially important prey are included in model inputs. Analysis of digestive tracts allows prey to be identified from hard structures such as fish otoliths or bones, cephalopod beaks, and polychaete jaws (Pierce and Boyle 1991). For SLE Beluga, opportunities to sample digestive tracts are limited to animals found dead, the majority of which have empty guts or contain only traces of food as they generally die after a period of anorexia (Lair *et al.* 2016). While these samples are unsuitable for quantitative diet assessment, they are valuable for identifying current prey species for comparison to the past and for other diet analyses. In the context of the recent population decline, identifying prey species may guide conservation actions important for SLE Beluga. Here, we examine the contemporary diet of SLE Beluga using digestive tracts collected from carcasses recovered over the past 30 years, in the context of historical diet data and recent changes in trophic structure of the St. Lawrence ecosystem.

Methods

Starting in 2007, digestive tracts were collected from well-preserved or moderately decomposed (freshness codes ≤3; Geracy and Lounsbury 1993) Beluga reported dead in the SLE and examined systematically for prey remains using standard protocols (Hammill *et al.* 2005). Sex and age were available for each individual; only individuals one year or older (i.e., likely to have ingested solid food; Brodie 1971; Matthews and Ferguson 2015) were included in the analysis. Age was determined from tooth dentinal layers, using a longitudinal midline section or half tooth, and high-resolution (4800 dpi optical resolution, 24-bit colour) digital imagery (Epson scanner Perfection V500 photo, Epson Canada Limited, Markham, Ontario, Canada) to allow for magnification, light, and contrast adjustments. One growth layer group (GLG) was assumed to be deposited each year (Stewart *et al.* 2006; Hohn *et al.* 2016; Waugh *et al.* 2018).

Digestive tracts were first examined for potential lesions. They were then extracted and frozen at –20°C until shipping and analysis for contents. They were confined to clean trays during the exam to avoid content loss. However, volume and mass of prey remains are likely to be imprecise due to digestion and are not reported here. Stomach and intestinal contents were examined separately but are presented in combination for this study. Each of the four stomach compartments were rinsed three times to ensure full recovery of contents. Stomach contents were then sorted using a fine mesh sieve (125 μm). Prey remains were identified to the lowest taxon possible using hard parts (i.e., otoliths and bones for fish, and beaks for cephalopods; Clarke 1986; Murie and Lavigne 1986).

Otoliths were assigned to one of three classes depending on degradation state. Class 1 included well preserved otoliths, Class 2 those eroded along margins but with few degradation marks, and Class 3 otoliths with erosion on both dorsal and ventral margins and internal and external areas. Prey size was estimated using otolith length/fish length relationships developed from samples collected during research cruises from Fisheries and Oceans Canada or using values from the literature (Bowen and Harrison 1996; Proust 1996; Hammill *et al.* 2007). A random subsample of 30 otoliths per species was measured when a large number of otoliths was present in a sample. Few Class 1 and 2 otoliths were obtained from the decaying Beluga carcasses; Class 3 otolith were also measured and reported separately to provide fish length minima. Given the small number of digestive tracts with some content (see Results), no attempt was made to quantify diet composition in terms of energy or mass contributions. Prey items were analyzed for frequency of occurrence only (Bowen and Harrison 1996). Empty stomachs were excluded from calculations.

Results

Between 2007 and 2019, 79 Beluga were examined systematically for prey remains. An additional 10 Beluga with prey remains sampled in the late 1980s (n = 2), mid-1990s (n = 2), and early 2000s (n = 6) were also included in this study. The sample (n = 89) was skewed toward females (61 females versus 28 males), mature individuals (87% were eight years or older), and ice-free months (only four carcasses collected during winter, i.e., December through March). Fifty-seven percent (45/79) of the systematically examined digestive tracts (i.e., 2007 onward) contained identifiable prey remains, with 13% (10/79) of the tracts having food in more than trace amounts, i.e., more than 15 otoliths or invertebrate parts.

Twenty-eight taxa, 18 fish and 10 invertebrate species, were represented in digestive tracts (Table 1; detailed diet data in Table S1). On average, 2.4 (SD = 2.2) prey species were detected per Beluga, although 11 different species were detected in one Beluga (nine fish, two invertebrates). Our limited data on fullness indices show no evidence for a fast and feast pattern over seasons in this population (Figure 2). Prey diversity in digestive tracts that contained food in amounts greater than trace, varied among months, but without following a clear seasonal pattern (Table 2). Both invertebrate and fish prey were detected in

TABLE 1. Species frequency of occurrence (% of digestive tracts with prey remains) in the diet of Beluga (*Delphinapterus leucas*) hunted mainly at the Banc de Manicouagan in 1938–1939 (Vladykov 1946: 60), or collected in various regions of the St. Lawrence Estuary via Beluga carcass recovery between 1989 and 2019 (our study).

Taxon	Vladykov 1938–1939		Our study 1989–2019	
	n	% (*n* = 107)	*n*	% (*n* = 59)
FISHES	107		36	
Ammodytidae				
Sand lance (*Ammodytes* sp.)	58	54	4	7
Clupeidae				
Atlantic Herring (*Clupea harengus*)	2	2	2	3
Osmeridae				
Capelin (*Mallotus villosus*)	54	51	7	12
Rainbow Smelt (*Osmerus mordax*)	1	1	4	7
Scombridae				
Atlantic Mackerel (*Scomber scombrus*)	—		1	2
Gadidae				
Atlantic Cod/Greenland Cod (*Gadus morhua*/*Gadus ogac*)	45	42	10	17
Atlantic Cod (*Gadus morhua*)	—		3	5
Atlantic Tomcod (*Microgadus tomcod*)	18	17	1	2
Haddock (*Melanogrammus aeglefinus*)	2	2	—	
White Hake (*Urophycis tenuis*)	—		5	8
Silver Hake (*Merluccius bilinearis*)	—		1	2
Red Hake (*Urophycis chuss*)	1	1	—	
Fourbeard Rockling (*Enchelyopus cimbrius*)	—		3	5
Ocean Pout (*Zoarces americanus*)/*Lycodes* sp.	2	2	2	3
Gadidae (unspecified)	—		5	8
Macrouridae				
Marlin-spike (*Nezumia bairdii*)	—		2	3
Scorpaenidae				
Redfish (*Sebastes* sp.)	—		9	15
Cyclopteridae				
Snailfish (*Liparis* sp.)*	4	4	1	2
Lumpfish (*Cyclopterus lumpus*)	1	1	1	2
Cottidae				
Sculpins (*Myoxocephalus* sp.)	35	33	1	2
Daubed Shanny (*Leptoclinus maculatus*)	—		1	2
Cottidae (unspecified)	—		3	5
Anguillidae				
American Eel (*Anguilla rostrata*)†	—		1	2
Pleuronectidae				
Witch Flounder (*Glyptocephalus cynoglossus*)	1	1	—	
Winter Flounder (*Pseudopleuronectes americanus*)	9	9	1	2
Smooth Flounder (*Pleuronectes putnami*)	5	5	1	2
Rajidae				
Smooth and Thorny Skate (*Malacoraja senta*, *Amblyraja radiata*, and skate sp.)	6	6	—	
Petromyzontidae				
Sea Lamprey (*Petromyzon marinus*)	2	2	—	
Acipenseridae				
Atlantic Sturgeon (*Acipenser oxyrinchus*)	3	3	—	

TABLE 1. *Continued.*

Taxon	Vladykov 1938–1939		Our study 1989–2019	
	n	% (n = 107)	n	% (n = 59)
Salmonidae				
Atlantic Salmon (*Salmo salar*)	1	1	—	
INVERTEBRATES	91		28	
Polychaeta				
polychaete worm (*Nereis virens*)	64	60	23	39
Cistenides gouldii	22	21	—	
Crustacea				
Decapod shrimp	69	65	9	15
Amphipod gammarid	37	35	1	2
Other	4	4	—	
Mollusca				
Gastropods Waved Whelk (*Buccinum undatum*) and periwinkle (*Littorina* sp.)	19	18	4	7
Bivalvia lamellibranch (*Cyrtodaria*/*Mesodesma*)	37	35	1	2
Cephalopod Northern Shortfin Squid (*Illex illecebrosus*)	35	33	5	8
Cephalopod Northern Atlantic Octopus (*Bathypolypus bairdii*)‡	21	20	3	5
Cephalopod (unspecified)	—		2	3
Other	68	64	—	

*Named *Neoliparis atlanticus* in Vladykov (1946).
†Most likely identification from eroded otolith.
‡*Bathypolypus obesus* in Vladykov (1946).

digestive tracts (Table 1). Fish with the highest occurrences were demersal species, i.e., cod (either or both *G. morhua* and *G. ogac*), redfish (*Sebastes* sp.) and hake (White [*Urophycis tenuis*] and Silver [*Merluccius bilinearis*] Hake), with occurrences varying from 10 to 22%. Small pelagic or bottom-dwelling species such as Capelin (*Mallotus villosus*), sand lance (*Ammodytes* sp.), and Rainbow Smelt (*Osmerus mordax*) were present in 12, 7, and 7% of the tracts, respectively. Among invertebrates, polychaete worms were the most common prey with a 39% occurrence, followed by decapod shrimp (15%) and Northern Shortfin Squid (8%).

There was no clear seasonal trend in different prey occurrences in SLE Beluga in general or by sex (not shown). However, some patterns emerged when examining prey assemblages in individual Beluga per sector/month. Except for one adult male sampled at Rivière-Ouelle (upper estuary) in early May, which contained 1933 Capelin otoliths, all other Beluga sampled in the upper estuary between June and September (n = 8) were adult females. The females fed on small pelagic or bottom-dwelling fish such as Capelin, sand lance, Atlantic Herring (*Clupea harengus*) or Rainbow Smelt, on Northern Shortfin Squid and polychaete worms, and on prey not reported elsewhere in the SLE, which included Atlantic Tomcod (*Microgadus tomcod*), Smooth Flounder (*Pleuronectes putnami*), and Winter Flounder (*Pseudopleuronectes americanus*). Although some Beluga found dead in the lower estuary might have drifted there from the upper estuary, lower estuary Beluga differed from upper estuary Beluga by including both females and males that contained multiple demersal fish species, including cod (Atlantic or Greenland Cod), redfish, and White and Silver Hake. Note that while Atlantic Cod were specifically identified among prey remains in three samples, cod otoliths in seven other samples were too eroded to be identified to species as Atlantic or Greenland Cod.

Polychaete worms, Capelin, hakes, and cephalopods (Northern Shortfin Squid or Northern Atlantic Octopus [*Bathypolypus bairdii*]) followed no clear gender-based, seasonal, or spatial trends in our sample. However, some species showed a seasonal pattern in Beluga digestive tracts: American Eels were detected only in October (one Beluga); sand lance and Atlantic Herring only in April or September samples; and Rainbow Smelt only in April, and then from late August through October (Figure 3). Demersal fish species from the families Zoarcidae, Macrouridae, Liparidae, Cyclopteridae, and Cottidae, were found in trace amounts in samples, and only outside of summer months, i.e., in April, May, and from September

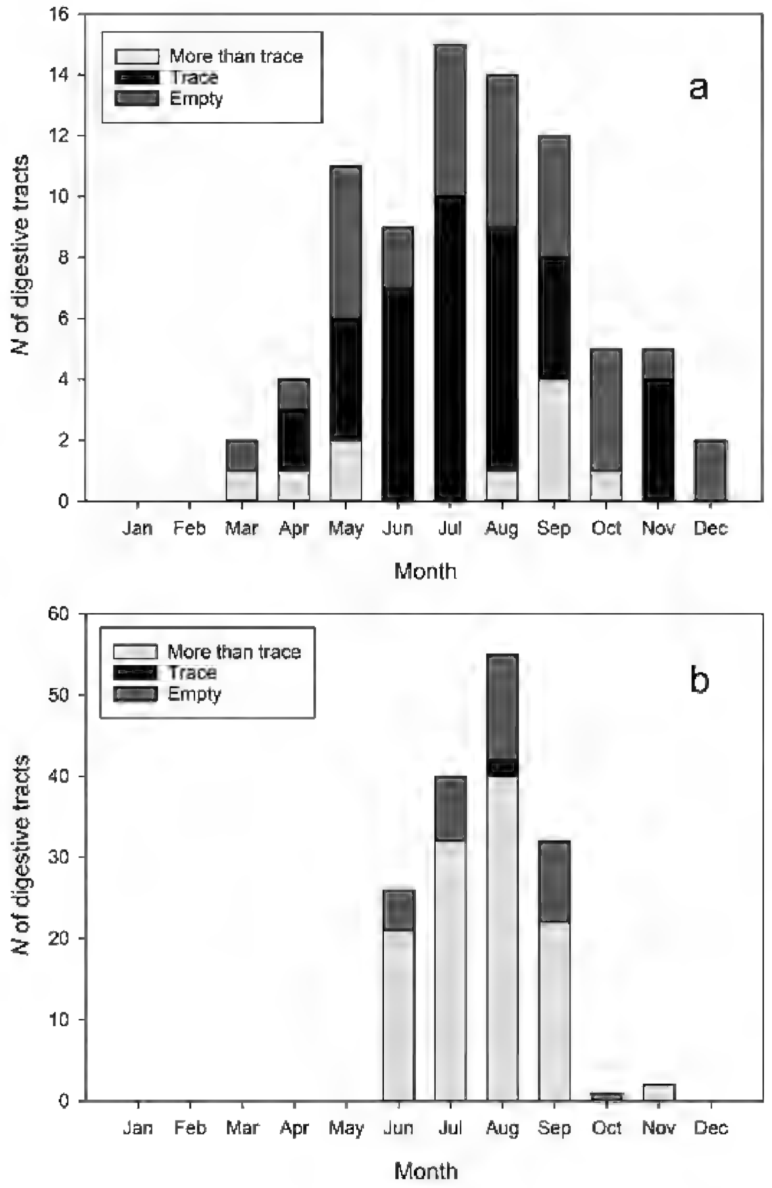


FIGURE 2. Seasonal distribution of Beluga (*Delphinapterus leucas*) digestive tract sampling in a. our study (2007 and onward) and b. that of Vladykov (1946), and relative index of contents volume. A 'Trace' content had fewer than 15 otoliths or invertebrate identifiable parts.

TABLE 2. Monthly diet diversity expressed as the mean number of taxa detected in digestive tracts containing prey remains in more than trace amounts (≥15 hard parts) for St. Lawrence Estuary Beluga (*Delphinapterus leucas*) hunted at three different sites in the late 1930s (Vladykov 1946; see Figure 1), or found dead between 1983 and 2019 (our study). Sample size is indicated in parentheses.

Month	Our study (n = 16)	Vladykov (1946)		
		Manicouagan (n = 89)	Les Escoumins (n = 16)	Rivière-Ouelle (n = 2)
Jan	—	—	—	—
Feb	—	—	—	—
Mar	2 (1)	—	—	—
Apr	6 (1)	—	—	—
May	2 (3)	—	—	—
June	—	2.8 (13)	6.3 (7)	—
July	5 (1)	3.9 (24)	6 (8)	—
Aug	3.5 (2)	7.3 (31)	7 (1)	—
Sep	5.8 (5)	5.2 (21)	—	—
Oct	7 (2)	—	—	—
Nov	4 (1)	—	—	5 (2)
Dec	—	—	—	—

through November. Males consumed redfish in all sampled seasons, while females only in April, or September and October (Figure 4).

The estimated overall mean length of prey found in SLE Beluga digestive tracts using unworn or moderately worn otoliths was 19.8 cm (SE = 1.2 cm, n = 97, range 5.9–54.8 cm), and when including worn otoliths was 20.3 cm (SE = 0.4 cm, n = 533, range 4.6–54.8 cm). This mean value changed little (by 0.4–0.5 cm) depending on whether cod otoliths were assumed to be Atlantic or Greenland Cod. The smallest fish consumed were Capelin with a mean length of 11.4 cm (SE = 0.15 cm; n = 49), while the largest were White Hake with a mean length of 45.9 cm (SE = 2.97 cm; n = 4). With the exception of Atlantic/Greenland Cod and hake, most Beluga preys were on average 30 cm or less in length (Table 3, Figure 5).

Discussion

A variety of physiological and ecological factors can influence prey selection, energy intake, and feeding strategies of marine predators like Beluga (Stephens and Krebs 1986). These include prey availability and energy content, the predator's energy requirements, behavioural and physiological constraints such as those that body size or the presence of a dependant calf impose on prey type and size, and on dive duration and depth (Salton *et al.* 2019). Seasonal and spatial patterns that are observed in diet composition among populations or among individuals of different reproductive, age, or sex classes likely reflect some of these constraints.

The Estuary and Gulf of St. Lawrence like other ecosystems worldwide have undergone profound ecosystemic changes as a result of overfishing and ocean warming (Worm and Myers 2003; Stenseth *et al.* 2004). An analysis incorporating 94 physical and biological variables over a 40-year period for the Gulf of St. Lawrence underscored the massive drop in demersal fish biomass in the early 1990s, the increase in atmospheric and water temperatures, and decrease in sea ice extent and thickness since 2000, with extremes recorded since 2010 (Plourde *et al.* 2014). While we know little about prey abundance in the 1930s, environmental changes since the 1990s likely affected Beluga prey availability in recent times. The abundance of potential competitors to SLE Beluga also changed since the 1930s. They include Harp Seals, Grey Seals, juvenile Harbour Seals (*Phoca vitulina*), and female Hooded Seals (*Cystophora cristata*),

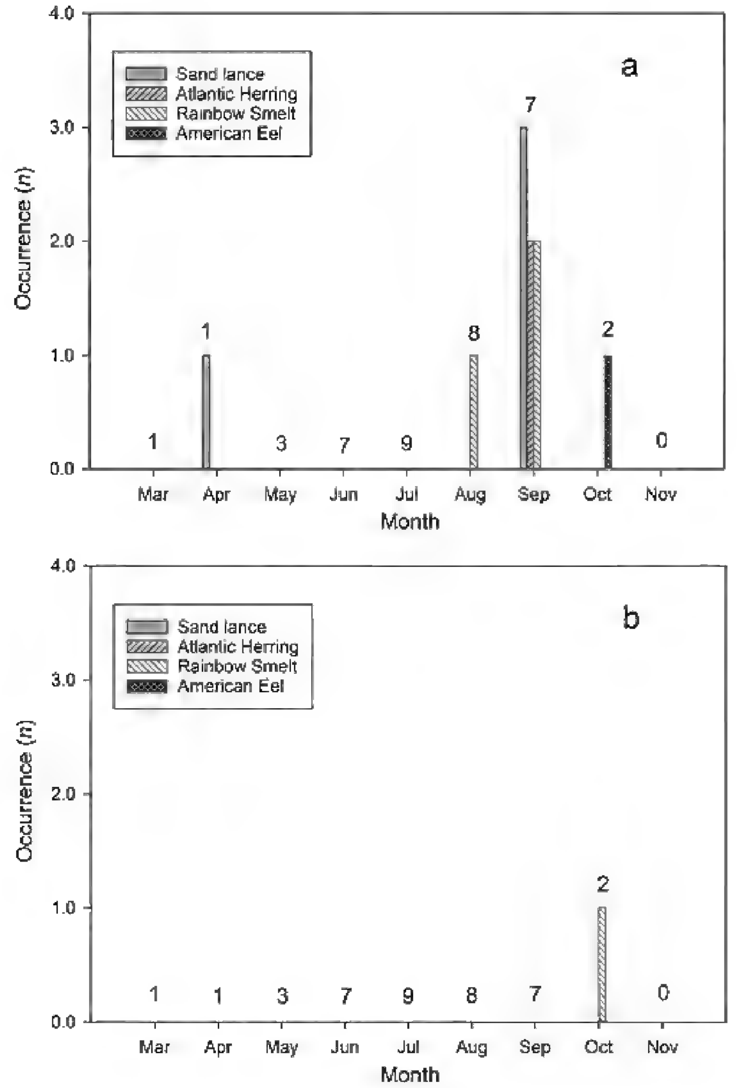


FIGURE 3. Seasonal occurrence of Sand lance (*Ammodytes* sp.), Atlantic Herring (*Clupea harengus*), Rainbow Smelt (*Osmerus mordax*), and American Eel (*Anguilla rostrata*) in digestive tracts of a. female and b. male St. Lawrence Estuary Beluga (*Delphinapterus leucas*) collected between 1988 and 2019. Numbers of tracts with at least trace amounts of food are indicated above each set of bars.

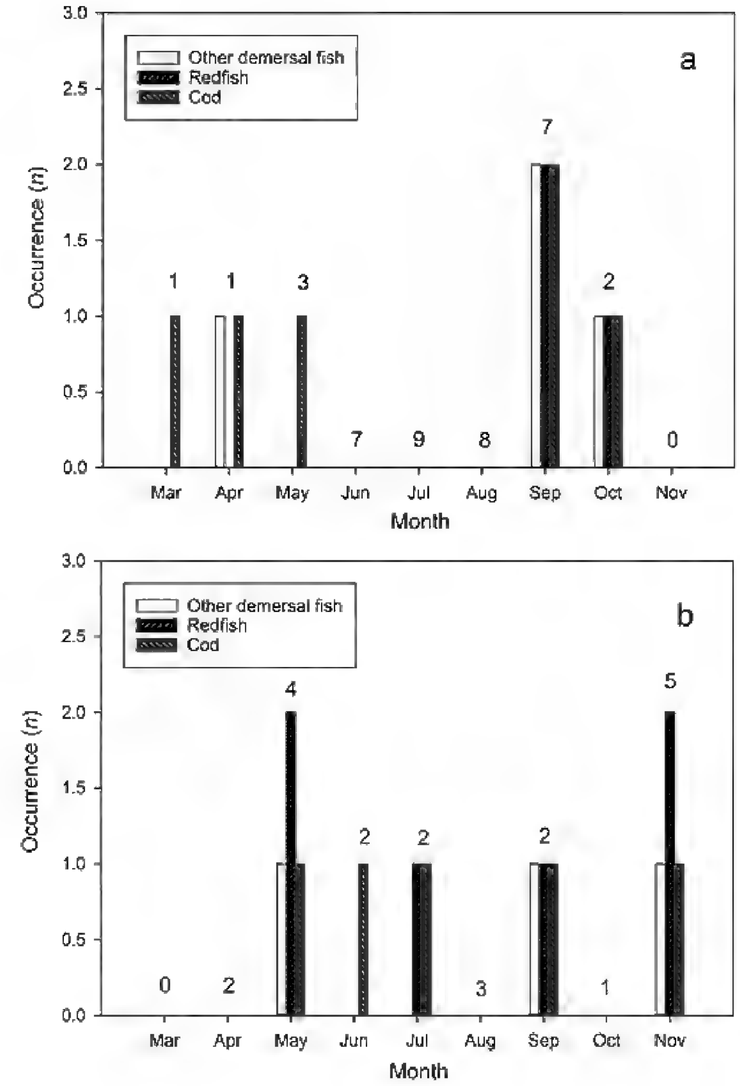


FIGURE 4. Seasonal occurrence of redfish (*Sebastes* spp.), cod species (either *Gadus morhua* or *Gadus ogac*), and other demersal fish species from the families Zoarcidae, Macrouridae, Liparidae, Cyplopteridae, and Cottidae in digestive tracts of a. female and b. male St. Lawrence Estuary Beluga (*Delphinapterus leucas*) collected between 1988 and 2019. Numbers of tracts with at least trace amounts of food are indicated above each set of bars.

which occupy trophic positions similar to adult female and male Beluga (Lesage *et al.* 2001). Baleen whales occupy lower trophic positions but share prey items with Beluga (Gavrilchuk *et al.* 2014). Several of these populations are increasing in size (Stevick *et al.* 2003; Hammill and Stenson 2006; Hammill *et al.* 2010, 2015, 2017), but competition extent has not been documented.

Similarities but also differences were observed when comparing present and past diet of SLE Beluga. Sand lance and Capelin were prey with the highest occurrences in SLE Beluga stomachs in the 1930s (Vladykov 1946), while large demersal fish such as cod, hake, and redfish were the most frequent fish prey in our study. Redfish, American Eel, and two species of hake were present in Beluga contemporary diet but were undetected in Vladykov's study. The reverse was noted for Atlantic Salmon (*Salmo salar*), Atlantic Sturgeon (*Acipenser oxyrinchus*), Sea Lamprey (*Petromyzon marinus*), Haddock (*Melanogrammus aeglefinus*), and skates. Polychaete worms and cephalopods were frequently ingested invertebrates in both studies. There was no obvious bias or difference in age- or sex-class sampling in Vladykov's nor our study; adults from both sexes were well represented in both studies, along with lower occurrences of calves and juveniles. However, sampling timing and location might explain some of the observed differences among studies; for instance, American Eel is more likely to be abundant in the fall in the SLE, particularly in the upper estuary (e.g., Vladykov 1946) or in the Saguenay River—times and places that were not sampled by Vladykov. Whether the absence of hake and redfish in Vladykov's study results from the strong sampling bias toward a sandy habitat no longer used by Beluga (the Manicouagan River mouth) or to a change in their availability over time is unknown. Temporal trend data for redfish are relatively recent; two summer studies from the 1930s and 1950s suggest that redfish were scarce in the SLE in the 1930s (Vladykov and Tremblay 1935 as cited in Steele 1957).

TABLE 3. Average (± SE) fork length for Beluga (*Delphinapterus leucas*) prey, based on otolith length that were well preserved and moderately eroded (Class 1 and 2, respectively), and including eroded otoliths (all classes).

Species	Class 1 and 2		All classes	
	Mean length (cm)	*n*	Mean length (cm)	*n*
Sand lance (*Ammodytes* sp.)	13.2	1	12.1 (0.46)	8
Atlantic Herring (*Clupea harengus*)	28.5 (0.85)	10	23.6 (1.64)	20
Fourbeard Rockling (*Enchelyopus cimbrius*)	—		22.4 (3.05)	5
Atlantic Cod (*Gadus morhua*)	—		33.7 (4.75)	7
Atlantic Cod/Greenland Cod (*Gadus morhua/Gadus ogac*)	40.8 (0.91)	10	30.0 (0.71)	137
Daubed Shanny (*Leptoclinus maculatus*)	—		—	
Lycodes (*Lycodes* sp.)	—		28.2 (1.16)	5
Capelin (*Mallotus villosus*)	11.4 (0.15)	49	12.7 (0.22)	90
Silver Hake (*Merluccius bilinearis*)	—		29.6 (0.57)	26
Marlin-pike (*Nezumia bairdii*)	—		23.4 (0.62)	10
Rainbow Smelt (*Osmerus mordax*)	—		10.7 (0.26)	101
Redfish (*Sebastes* sp.)	—		20.2 (0.40)	92
Deepwater Redfish (*Sebastes mentella*)	18.5 (0.63)	14	—	
White Hake (*Urophycis tenuis*)	—		45.9 (2.97)	4

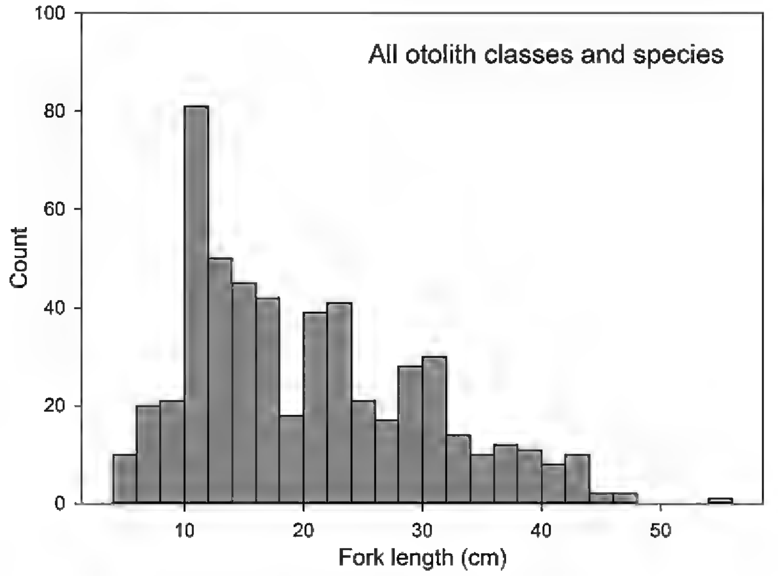


FIGURE 5. Frequency distribution of fish size estimated from the length of 533 otoliths recovered from digestive tracts of St. Lawrence Estuary Beluga (*Delphinapterus leucas*) that were found dead between 1988 and 2019. All otoliths that allowed identification of species (i.e., regardless of degree of degradation) were included in this analysis.

Otoliths are calcium carbonate structures that progressively deteriorate when exposed to gastric fluids, and at a different rate depending on size and robustness (Tollit *et al.* 1997). Our reliance on decomposing carcasses reduced the chances of detecting small otoliths that are typical of smaller species (e.g., sand lance and Capelin), possibly biasing prey relative occurrences. In contrast, cephalopod beaks and hard parts of polychaete worms can accumulate over a few meals, possibly overestimating their importance (Jobling and Breiby 1986; Tollit *et al.* 1997). While the presence of some benthic invertebrates in digestive tracts might have resulted from secondary ingestion or suction feeding on other prey, others such as Northern Atlantic Octopus, Northern Shortfin Squid, polychaete worms, and shrimp were in volumes compatible with direct ingestion (Vladykov 1946; Seaman *et al.* 1982; Lowry *et al.* 1985; Quakenbush *et al.* 2015).

Our study confirmed SLE Beluga past (Vladykov 1946) and present have a varied diet as they do elsewhere (Kleinenberg *et al.* 1964; Seaman *et al.* 1982; Heide-Jorgensen and Teilmann 1994; Hobbs *et al.* 2008; Quakenbush et al. 2015). Capelin was the most important prey for Beluga during early summer, with sand lance and demersal fish such as cod progressively replacing Capelin in late summer and early fall as water warmed, suggesting some seasonality in prey selection or availability (Vladykov 1946). There was no seasonal pattern detected in Capelin occurrence in our study. Spawning for Capelin begins around mid-April in the upper estuary and lasts until the end of June in the lower estuary (Jacquaz *et al.* 1977). The dominance of Capelin in our March and May samples supports their importance for Beluga at that period, but whether their ingestion is supplemented with other species at these times is unknown. There was evidence of seasonality for sand lance but also other species in our study. Sand lance along with American Eel, Rainbow Smelt, and Atlantic Herring were detected in Beluga diets exclusively in late summer and fall, whereas other species from the families Zoarcidae, Macrouridae, Liparidae, Cyclopteridae, and Cottidae were detected in spring and/or fall. The coincidence of SLE Beluga aggregation areas with

sand lance habitat is also evidence for potential use of this species in recent years (Mosnier *et al.* 2016).

The St. Lawrence Estuary is a highly heterogeneous and dynamic environment, with expected effects on prey community structure and availability. The upper estuary is an area of shallow, warm water of relatively low salinity (<26 ppm), whereas the lower estuary consists of the deep, cold, and saline water of the Laurentian Channel, and the shallower water of intermediate salinity and temperature of the south shore (El-Sabh *et al.* 1979; Figure 1). While some prey, such as Capelin, Atlantic Herring, and sand lance, are relatively abundant in both sectors, others are more abundant in, or are exclusive to, one or the other. This is the case for Atlantic Tomcod, American Eel, Smooth Flounder, American Shad (*Alosa sapidissima*), and Rainbow Smelt, that occur mainly, or are more abundant, in the upper estuary (Bourget 2011). Conversely, redfish, cod, hake, poachers, Greenland Halibut (*Reinhardtius hippoglossoides*), Northern Shortfin Squid, Sea Lamprey, lycodes, American Plaice (*Hippoglossoides platessoides*), and most skate species are more abundant or found exclusively in the lower estuary (Scallon-Chouinard *et al.* 2007).

The upper and lower estuary are used differentially by adult male and female Beluga during summer, consistent with the sex- and age-class spatial segregation documented for the species (Michaud 1993; Smith and Martin 1994; Smith *et al.* 1994; Richard *et al.* 1997; Heide-Jorgensen and Lockyer 2001; Loseto *et al.* 2006, 2008). In the SLE, adult females and juveniles use primarily the upper estuary and south shore of the lower estuary during summer, while large individuals (presumed to be adult males) concentrate mainly in the lower estuary (Michaud 1993; Figure 1). Adult males overlap with females and juveniles in the shallower waters of the lower estuary, and in the Saguenay River and river mouth. Our upper estuary sample was dominated by females (7/8 carcasses) that had fed on a mix of small pelagic or bottom-dwelling fish and less on demersal fish. Our lower estuary sample was composed of individuals from both sexes, that had fed on multiple species of demersal fish. Isotopic mass balance models using a preliminary set of prey support the greater importance of demersal fish in the diet of males than females (Lesage 2014). These findings are also consistent with sex-specific isotopic and fatty acid signatures of SLE Beluga, and occupancy of higher trophic positions by males than females (Lesage *et al.* 2001; Nozères 2006; Lesage 2014).

Whether the spatial segregation among age and sex classes, with associated consequence on diet composition, extends in the spring and fall remains unclear. There is genetic evidence for a persistence of female-close kin, and male-male associations during the fall migration (Colbeck *et al.* 2013), although groups may share the same migration routes. In the SLE, support for a reduced spatial segregation outside summer comes from historical fall hunts of large adults (likely males) at Rivière-Ouelle in the upper estuary (Vladykov 1944), the spring report of a dead adult male full of Capelin in the same area (our study), and the concentration of most spring Beluga observations in the upper estuary (Michaud and Chadenet 1990). An overlap in distribution would make differential access to local prey communities less prominent outside summer, a prediction consistent with the lack of clear differences in diet composition between males and females in the spring and fall. The appearance of demersal fish in the female diet in spring or fall (while males consumed these species in all seasons) might reflect their greater use of the lower estuary outside of summer.

Beluga are size dimorphic, with males being larger than females (Lesage *et al.* 2014). Allometric relationships predict that males would be able to ingest larger prey items and a wider range of species (Wilson 1975), and reach deeper depths than females (Schreer and Kovacs 1997), predictions that were verified in other Beluga populations (Seaman *et al.* 1982; Lowry *et al.* 1985; Szpak *et al.* 2019). In the SLE, differential prey access by sexes due to diving capacity is unlikely given that maximum bottom depth (350 m) is shallower than the species diving capacity (in excess of 1100 m; Richard *et al.* 1997). While our sample was too small to document sex differences in ingested prey size, Vladykov (1946) reported adult males ingested larger fish such as cod and sculpins, and females ate smaller prey such as squid, polychaete worms, and sand lance more frequently. Beluga swallow prey whole (Quakenbush *et al.* 2015), and feed using suction (Brodie 1969), a strategy particularly efficient for capturing squid or capelin (Werth 2000) or when feeding on benthic or concealed prey such as sand lance and polychaete worms (Kane and Marshall 2009), where substrate enhances effective suction distances (Nauwelaerts *et al.* 2008). While suction feeding may theoretically limit prey size, as suggested by Vladykov (1946), reports of Alaskan Beluga ingesting whole Coho (*Oncorhynchus kisutch*) or Chum Salmon (*Oncorhynchus keta*) 60 cm or more in size (Quakenbush *et al.* 2015), suggest that SLE Beluga preference for prey <30 cm and on average 20 cm in length is unrelated to anatomical or feeding mode limitations.

Local prey availability likely explained the fall ingestion of American Eel, Rainbow Smelt, and Atlantic Tomcod as these catadromous or anadromous species are present or particularly abundant in the SLE at that time of year, especially in the upper

estuary (Casgrain 1873; Vladykov 1946; Bourget 2011). Atlantic Herring spawns in multiple localities in the SLE in both spring and fall (Munro *et al.* 1998) and are particularly lipid-rich just before spawning. The scarcity of Atlantic Herring in SLE Beluga diet in this study and that of Vladykov (1946) may reflect our inability to capture this short event in our sample, the mismatch between Vladykov sampling sites and Atlantic Herring spawning sites, or the preference of Beluga for laid eggs instead of Atlantic Herring themselves (i.e., absence of hard parts; Vladykov 1946). Observations of persistently large numbers of SLE Beluga (hourly average of 70 to 80 Beluga) in a known Atlantic Herring spawning area during spring spawning (late May; Lesage and Kingsley 1995), and hunter reports of Beluga eating substantial amounts of Atlantic Herring in the spring at Rivière-Ouelle and near Ile Verte (north of Rivière-du-Loup, Quebec, Canada; Vladykov 1946) highlight their likely importance for SLE Beluga at least at that time of year.

Beluga are considered opportunistic feeders, but there might be prey or feeding times that are key to their fitness and survival, even though there was no evidence of a cycle of fast and feast in either Vladykov's (1946) or our study (Figure 2). Peak calving is in July for SLE Beluga (Sergeant 1986), and captivity studies indicate that energy intake increases 1.5- to 2-fold during the last two months of pregnancy. It peaks at four times normal during the first month after birth and remains at 1.5 to 2 times normal for the following three months of lactation (Kastelein *et al.* 1994). Accordingly, energy demands on pregnant SLE Beluga females start rising in May and remain high through at least early fall. Casgrain (1873) reported that SLE Beluga at Rivière-Ouelle in the spring are thin and voracious, feeding on Capelin and Rainbow Smelt in such a way that they put on 13 to 15 cm, sometimes 20 cm of fat in 8–10 days. Although the reported gain in blubber thickness appears extreme, these observations suggest that spring feeding might be critical in SLE Beluga for replenishing fat stores just before entering the last months of the gestation and calving period. Vladykov (1946), based on condition and stomach fullness indices, suggest that Beluga are fat in June, less in July and August, and fatter again in September. If this is the case, then spring and fall spawning species such as Capelin and Atlantic Herring, and catadromous or diadromous prey such as Rainbow Smelt, and possibly the large demersal fish that gain in importance in female diet in the fall, might be important for Beluga. Capelin and sand lance are still present in the SLE (e.g., Dutil *et al.* 2009), but their abundance is unknown. In Newfoundland, Capelin stocks have collapsed in recent decades (Buren *et al.* 2019); whether similar patterns prevail in the SLE and Gulf of St. Lawrence is unknown (DFO 2015). Stock abundance of other species such as spring Atlantic Herring, Rainbow Smelt, American Eel, and Atlantic Cod, are known to be considerably reduced compared to historical levels (Mingelbier *et al.* 2001; DFO 2010, 2019; Swain 2016; Équipe de Rétablissement de l'Éperlan arc-en-ciel, population du sud de l'estuaire du Saint-Laurent 2019). Whether the SLE Beluga recent high female and calf mortality rates (Lair *et al.* 2016; Gosselin *et al.* 2017) and failure to recover since the 1980s might at least be partially related to inadequate access to lipid-rich food at crucial times cannot be dismissed, and warrants further investigation. In eastern Beaufort Sea Beluga, there are concerns that the low body condition index (based on blubber thickness) reported in recent years might be caused by a lower availability of Arctic Cod (*Boreogadus saida*; Choy *et al.* 2017), and ingestion of prey of a lower lipid quality requiring higher energy output for their capture (Loseto *et al.* 2018).

At a time when several Beluga populations worldwide are threatened by previous overhunting and habitat degradation (i.e., COSEWIC 2004; National Marine Fisheries Service 2016), access to information on current and past diet and seasonal feeding cycles is critical for predicting and mitigating potential impacts of anthropogenic activity and climate at times and places where they matter the most. While our sample size was too small to quantitatively evaluate the contemporary diet of SLE Beluga, our results indicate that fish from stocks believed to be depleted (Atlantic Cod, American Eel) or that are now recovering (Striped Bass, redfish) should be considered as possible prey and not dismissed from diet estimations using quantitative models based on molecular tracers, or when trying to understand current contamination sources affecting this population. Approaches for investigating diet should also consider seasonality in prey availability and quality, and inter-individual diet variability as mechanisms for reducing potential competition (Tinker *et al.* 2008).

Author Contributions

Writing – Original Draft: V.L.; Writing – Review & Editing: S.L., S.T., and P.B.; Conceptualization: V.L.; Investigation: V.L., S.L., S.T., and P.B.; Methodology: V.L. and S.T.; Formal Analysis: V.L. and S.T.; Funding Acquisition: V.L.

Acknowledgements

We thank Carl Guimont and Richard Plante from FILMAR Industries, and the many people who helped with collection of carcasses over the study period. We thank also Drs. Daniel Martineau, Christiane Girard, André Dallaire, Igor Mikaelian, Sylvain De

Guise, and the many students and technical staff from the University de Montréal Veterinary College who helped with Beluga necropsies over the years, as well as Dr. Lena Measures and the Réseau Québecois d'Urgence pour les Mammifères Marins for coordinating the carcass recovery network. Pierre Carter, Johanne Guérin, Pierre Rivard, Susan Crockford, and Roberta Miller assisted with the identification of prey remains, and J.-F. Ouellet produced the map. We thank Jory Cabrol and two anonymous reviewers for their help improving the manuscript. This study was supported by Fisheries and Oceans Canada and Parks Canada.

Literature Cited

Bourget, G. 2011. Réseau d'inventaire des poissons de l'estuaire (RIPE) – Bilan de l'année 2009. Ministère des Ressources naturelles et de la Faune, Direction de l'expertise Faune-Forets-Territoire, Direction générale du Bas-Saint-Laurent. Accessed 28 February 2020. http://collections.banq.qc.ca/ark:/52327/bs2433594.

Bowen, W.D. 1997. Role of marine mammals in aquatic ecosystems. Marine Ecology Progress Series 158: 267–274. https://doi.org/10.3354/meps158267

Bowen, W.D., and G.D. Harrison. 1996. Comparison of harbour seal diets in two inshore habitats of Atlantic Canada. Canadian Journal of Zoology 74: 125–135. https://doi.org/10/1139/z96-017

Brassard, C., H. Bourdages, D. Duplisia, J. Gauthier, and A. Valentin. 2017. The status of the redfish stocks (*Sebastes fasciatus* and *S. mentella*) in Unit 1 (Gulf of St. Lawrence) in 2015. DFO Canadian Science Advisory Secretariat, Research Document 2017/023. Accessed 28 February 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/40605243.pdf.

Brodie, P.F. 1969. Mandibular layering in *Delphinapterus leucas* and age determination. Nature 221: 956–958. https://doi.org/10.1038/221956a0

Brodie, P.F. 1971. A reconsideration of aspects of growth, reproduction, and behavior of the white whale (*Delphinapterus leucas*), with reference to the Cumberland Sound, Baffin Island, population. Journal of the Fisheries Research Board of Canada 28: 1309–1318. https://doi.org/10.1139/f71-198

Buren, A.J., H.M. Murphy, A.T. Adamack, G.K. Davoren, M. Koen-Alonso, W.A. Montevecchi, F.K. Mowbray, P. Pepin, P.M. Regular, D. Robert, G.A. Rose, G.B. Stenson, and D. Varkey. 2019. The collapse and continued low productivity of a keystone forage fish species. Marine Ecology Progress Series 616: 155–170. https://doi.org/10.3354/meps12924

Cairns, D.K., G. Chaput, L.A. Poirier, T.S. Avery, M. Castonguay, A. Mathers, J.M. Casselman, R.G. Bradford, T. Pratt, G. Verreault, K. Clarke, G. Veinott, and L. Bernatchez. 2014. Recovery potential assessment for the American eel (*Anguilla rostrata*) for eastern Canada: life history, distribution, reported landings, status indicators, and demographic parameters. DFO Canadian Science Advisory Secretariat, Research Document 2013/134. Accessed 6 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/360883.pdf.

Canada Gazette. 2016. Order amending Schedule 1 to the *Species at Risk Act*. Accessed 28 February 2020. http://canadagazette.gc.ca/rp-pr/p1/2016/2016-08-27/html/reg1-eng.html.

Casgrain, Abbé. 1873. La pêche aux marsouins dans le fleuve Saint-Laurent. Montréal. Published without author name. Accessed 28 February 2020. https://ia802906.us.archive.org/12/items/cihm_00526/cihm_00526.pdf.

Choy, E.S., B. Rosenberg, J.D. Roth, and L.L. Loseto. 2017. Inter-annual variation in environmental factors affect the prey and body condition of beluga whales in the eastern Beaufort Sea. Marine Ecology Progress Series 579: 213–225. https://doi.org/10.3354/meps12256

Clarke, M.R. 1986. A Handbook for the Identification of Cephalopod Beaks. Clarendon Press, Oxford, United Kingdom.

Colbeck, G.J., P. Duchesne, L.D. Postma, V. Lesage, M.O. Hammill, and J. Turgeon. 2013. Groups of related belugas (*Delphinapterus leucas*) travel together during their seasonal migrations in and around Hudson Bay. Proceedings of the Royal Society B: Biological Sciences 280: 20122552. https://doi.org/10.1098/rspb.2012.2552

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2004. COSEWIC assessment and update status report on the Beluga *Delphinapterus leucas* in Canada. COSEWIC, Ottawa, Ontario, Canada.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2012. COSEWIC assessment and status report on the Striped Bass *Morone saxatilis* in Canada. COSEWIC, Ottawa, Ontario, Canada.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2014. COSEWIC assessment and status report on the Beluga Whale *Delphinapterus leucas*, St. Lawrence Estuary population, in Canada. COSEWIC, Ottawa, Ontario, Canada.

DFO (Fisheries and Oceans Canada). 2010. Status of American Eel and progress on achieving management goals. DFO Canadian Science Advisory Secretariat, Science Advisory Report 2010/062. Accessed 6 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/342640.pdf.

DFO (Fisheries and Oceans Canada). 2014. Status of Beluga (*Delphinapterus leucas*) in the St. Lawrence River estuary. DFO Canadian Science Advisory Secretariat, Science Advisory Report 2013/076. Accessed 6 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/361043.pdf.

DFO (Fisheries and Oceans Canada). 2015. Update of indicators of the status of the Estuary and Gulf of St. Lawrence (Divisions 4RST) Capelin stock in 2014. DFO Canadian Science Advisory Secretariat, Science Response 2015/032. Accessed 6 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/363796.pdf.

DFO (Fisheries and Oceans Canada). 2017. Information in support of Critical Habitat identification for Striped Bass (*Morone saxatilis*) of the St. Lawrence River. DFO Canadian Science Advisory Secretariat, Science Advisory Report 2017/001. Accessed 6 April 2020.

https://waves-vagues.dfo-mpo.gc.ca/Library/40597234.pdf.

DFO (Fisheries and Oceans Canada). 2019. Assessment of Atlantic Cod (*Gadus morhua*) in the southern Gulf of St. Lawrence (NAFO Div. 4T-4Vn (Nov.–April)) to 2018. DFO Canadian Science Advisory Secretariat, Science Advisory Report 2019/021. Accessed 6 April 2020. http://www.dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2019/2019_021-eng.pdf.

Dutil, J.-D., C. Nozères, P.-M. Scallon-Chouinard, L. Van Guelpen, D. Bernier, S. Proulx, R. Miller, et C. Savenkoff. 2009. Poissons connus et méconnus des fonds marins du Saint-Laurent. Naturaliste canadien 133: 70–82.

El-Sabh, M.I., E. Bourget, M.J. Bewers, et J.-C. Dionne. 1979. L'océanographie de l'estuaire du Saint-Laurent. Naturaliste canadien 106: 1–276.

Équipe de Rétablissement de l'éperlan arc-en-ciel, population du sud de l'estuaire du Saint-Laurent. 2019. Bilan du rétablissement de l'éperlan arc-en-ciel (*Osmerus mordax*) au Québec, population du sud de l'estuaire du Saint-Laurent pour la période 2008–2016. Le ministère des Forêts, de la Faune et des Parcs, Direction générale de la gestion de la faune et des habitats. Quebec, Canada. Accessed 16 December 2019. https://mffp.gouv.qc.ca/documents/faune/bilan_retablissement_eperlan_arc-en-ciel_2008-2016.pdf.

Gavrilchuk, K., V. Lesage, C. Ramp, R. Sears, M. Bérubé, S. Bearhop, and G. Beauplet. 2014. Trophic niche partitioning among sympatric baleen whale species following the collapse of groundfish stocks in the Northwest Atlantic. Marine Ecology Progress Series 497: 285–301. https://doi.org/10.3354/meps10578

Geracy, J.R., and V.J. Lounsbury. 1993. Marine Mammals Ashore: a Field Guide for Strandings. Texas A&M Sea Grant College Program, Galveston, Texas, USA.

Gosselin, J.-F., M.O. Hammill, A. Mosnier, and V. Lesage. 2017. Abundance index of St. Lawrence Estuary beluga, *Delphinapterus leucas*, from aerial visual surveys flown in August 2014 and an update on reported deaths. DFO Canadian Science Advisory Secretariat, Research Document 2017/019. Accessed 6 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/40603854.pdf.

Hammill, M.O., W.D. Bowen, and B. Sjare. 2010. Status of Harbour Seals (*Phoca vitulina*) in Atlantic Canada. NAMMCO Scientific Publications 8: 175–190. https://doi.org/10.7557/3.2684

Hammill, M.O., C.E. den Heyer, W.D. Bowen, and S.L.C. Lang. 2017. Grey Seal population trends in Canadian waters, 1960–2016 and harvest advice. DFO Canadian Science Advisory Secretariat, Research Document 2017/052. Accessed 6 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/40643542.pdf.

Hammill, M.O., V. Lesage, and P. Carter. 2005. What do harp seals eat? Comparing diet composition from different compartments of the digestive tract with diets estimated from stable isotope ratios. Canadian Journal of Zoology 83: 1365–1372. https://doi.org/10.1139/Z05-123

Hammill, M.O., and G.B. Stenson. 2006. Abundance of Northwest Atlantic hooded seals (1960–2005). DFO Canadian Science Advisory Secretariat, Research Document 2006/068. Accessed 6 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/329037.pdf.

Hammill, M.O., G.B. Stenson, T. Doniol-Valcroze, and A. Mosnier. 2015. Conservation of Northwest Atlantic harp seals: past success, future uncertainty? Biological Conservation 192: 181–191. https://doi.org/10.1016/j.biocon.2015.09.016

Hammill, M.O., G.B. Stenson, F. Proust, P. Carter, and D. McKinnon. 2007. Feeding by grey seals in the Gulf of St. Lawrence and around Newfoundland. NAMMCO Scientific Publications 6: 135–152. https://doi.org/10.7557/3.2729

Harington, C.R. 1977. Marine mammals in the Champlain Sea and the Great Lakes. Annals of the New York Academy of Science 288: 508–537. https://doi.org/10.1111/j.1749-6632.1977.tb33640.x

Heide-Jørgensen, M.-P., and C. Lockyer. 2001. Age and sex distributions in the catches of Belugas, *Delphinapterus leucas*, in West Greenland and in western Russia. Mammalian Biology 66: 215–227.

Heide-Jørgensen, M.P., and J. Teilmann. 1994. Growth, reproduction, age structure and feeding habits of white whales (*Delphinapterus leucas*) in West Greenland waters. Meddelelser om Grøenland Bioscience 39: 195–212.

Hickie, B.E., M.C.S. Kingsley, P.V. Hodson, D.C.G. Muir, P. Béland, and D. Mackay. 2000. A modelling-based perspective on the past, present, and future polychlorinated biphenyl contamination of the St. Lawrence beluga whale (*Delphinapterus leucas*) population. Journal of Fisheries and Aquatic Sciences 57(Supplement 1): 101–112. https://doi.org/10.1139/f99-242

Hobbs, R.C., K.E.W. Shelden, D.J. Rugh, and S.A. Norman. 2008. Status review and extinction risk assessment of Cook Inlet belugas (*Delphinapterus leucas*). Alaska Fisheries Science Center, NOAA, National Marine Fisheries Service, 7600 Sand Point. Accessed 28 February 2020. https://www.afsc.noaa.gov/Publications/ProcRpt/PR%202006-16.pdf.

Hohn, A.A., C. Lockyer, and M. Acquarone. 2016. Report of the workshop on age estimation in monodontids. Tampa, FL, USA. 26–27 November 2011. https://doi.org/10.7557/3.3743

Iverson, S.J., C. Field, W.D. Bowen, and W. Blanchard. 2004. Quantitative fatty acid signature analysis: a new method of estimating predator diets. Ecological Monographs 74: 211–235. https://doi.org/10.1890/02-4105

Jacquaz, B., K.W. Able, and W.C. Leggett. 1977. Seasonal distribution, abundance, and growth of larval capelin (*Mallotus villosus*) in the St. Lawrence Estuary and northwestern Gulf of St. Lawrence. Journal of the Fisheries Research Board of Canada 34: 2008–2014. https://doi.org/10.1139/cjfas-2013-0227

Jobling, M., and A. Breiby. 1986. The use and abuse of fish otoliths in studies of feeding habits of marine piscivores. Sarsia 71: 265–274. https://doi.org/10.1080/00364827.1986.10419696

Kane, E.A., and C.D. Marshall. 2009. Comparative feeding kinematics and performance of odontocetes Belugas, Pacific white-sided dolphins and long-finned pilot whales. Journal of Experimental Biology 212:

3939–3950. https://doi.org/10.1242/jeb.034686

Kastelein, R.A., J. Ford, E. Berghout, P.R. Wiepkema, and M. van Boxsel. 1994. Food consumption, growth and reproduction of belugas (*Delphinapterus leucas*) in human care. Aquatic Mammals 20: 81–97.

Kleinenberg, S.E., A. Yablokov, B.M. Belkovich, and M.N. Tarasevich. 1964. Beluga (*Delphinapterus leucas*): investigation of the species. Israel Program for Scientific Translations, Jerusalem, No. TT-67-51345 (original publication in Russian).

Lair, S., L.N. Measures, and D. Martineau. 2016. Pathological findings and trends in mortality in the beluga (*Dephinapterus leucas*) population of the St. Lawrence Estuary, Québec, Canada, from 1983 to 2012. Veterinary Pathology 53: 22–36. https://doi.org/10.1177/0300985815604726

Lesage, V. 2014. Trends in the trophic ecology of St. Lawrence beluga (*Delphinapterus leucas*) over the period 1988–2012, based on stable isotope analysis. DFO Canadian Science Advisory Secretariat, Research Document 2013/126. Accessed 6 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/361182.pdf.

Lesage, V., M.O. Hammill, and K.M. Kovacs. 2001. Marine mammals and the community structure of the Estuary and Gulf of St. Lawrence, Canada: evidence from stable isotope analysis. Marine Ecology Progress Series 210: 203–221.

Lesage, V., et M.C.S. Kingsley. 1995. Bilan des connaissances de la population de bélugas (*Delphinapterus leucas*) du Saint-Laurent. Rapport technique canadien des sciences halieutiques et aquatiques 2041. Accessed 5 March 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/184023.pdf.

Lesage, V., L. Measures, A. Mosnier, S. Lair, and P. Béland. 2014. Mortality patterns in St. Lawrence Estuary beluga (*Delphinapterus leucas*), inferred from the carcass recovery data, 1983–2012. DFO Canadian Science Advisory Secretariat, Research Document 2013/118. Accessed 6 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/361254.pdf.

Loseto, L.L., J.D. Brewster, S.K. Ostertag, K. Snow, S.A. MacPhee, D.G. McNicholl, E.S. Cho, C. Giraldo, and C.A. Hornby. 2018. Diet and feeding observations from an unusual beluga harvest in 2014 near Ulukhaktok, Northwest Territories, Canada. Arctic Science 4: 421–431. https://doi.org/10.1139/as-2017-0046

Loseto, L.L., P. Richard, G.A. Stern, J. Orr, and S.H. Ferguson. 2006. Segregation of Beaufort Sea beluga whales during the open-water season. Canadian Journal of Zoology 84: 1743–1751. https://doi.org/10.1139/z06-160

Loseto, L.L., G.A. Stern, and S.H. Ferguson. 2008. Size and biomagnification: how habitat selection explains beluga mercury levels. Environmental Science and Technology 42: 3982–3988. https://doi.org/10.1021/es7024388

Lowry, L.F., K.J. Frost, and G.A. Seaman. 1985. Investigations of belukha whales in coastal waters of western and northern Alaska. III. Food habits. Alaska Department of Fish and Game, Fairbanks, Alaska. Accessed 28 February 2020. http://www.adfg.alaska.gov/static/home/library/pdfs/wildlife/federal_aid/85_lowry_etal_belukha_western_northern_ak_phase_i.pdf.

Matthews, C.J.D., and S.H. Ferguson. 2015. Weaning age variation in beluga whales (*Delphinapterus leucas*). Journal of Mammalogy 96: 425–437. https://doi.org/10.1093/jmammal/gyv046

Michaud, R. 1993. Distribution estivale du béluga du Saint-Laurent; synthèse 1986 à 1992. Rapport technique canadien des sciences halieutiques et aquatiques 1906. Accessed 28 February 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/145880.pdf.

Michaud, R., et V. Chadenet. 1990. Survols aériens pour l'estimation de la distribution printanière des bélugas du Saint-Laurent. INESL, Rimouski (QC). GREMM, Tadoussac, Quebec, Canada.

Mingelbier, M., F. Lecomte, and J.J. Dodson. 2001. Climate change and abundance cycles of two sympatric populations of smelt (*Osmerus mordax*) in the middle estuary of the St. Lawrence river, Canada. Canadian Journal of Fisheries and Aquatic Sciences 58: 2048–2058. https://doi.org/10.1139/cjfas-58-10-2048

Moore, J.W., and B.X. Semmens. 2008. Incorporating uncertainty and prior information into stable isotope mixing models. Ecology Letters 11: 470–480. https://doi.org/10.1111/j.1461-0248.2008.01163.x

Mosnier, A., T. Doniol-Valcroze, J.-F. Gosselin, V. Lesage, L.M. Measures, and M.O. Hammill. 2015. Insights into processes of population decline using an integrated population model: the case of the St. Lawrence beluga (*Delphinapterus leucas*). Ecological Modelling 314: 15–31. https://doi.org/10.1016/j.ecolmodel.2015.07.006

Mosnier, A., R. Larocque, M. Lebeuf, J.-F. Gosselin, S. Dubé, V. Lapointe, V. Lesage, D. Lefaivre, S. Senneville, et C. Chion. 2016. Définition et caractérisation de l'habitat du béluga (*Delphinapterus leucas*) de l'estuaire du Saint-Laurent selon une approche écosystémique. Secrétariat canadien de consultation scientifique du MPO, Document de recherche 2016/052. Accessed 6 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/365829.pdf.

Munro, J., D. Gauthier, et J.A. Gagné. 1998. Description d'une frayère de hareng (*Clupea harengus* L.) à l'île-aux-Lièvres dans l'estuaire moyen du Saint-Laurent. Rapport technique canadien des sciences halieutiques et aquatiques 2239. Accessed 28 February 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/229992.pdf.

Murie, D.J., and D.M. Lavigne. 1986. Interpretation of otoliths in stomach content analyses of phocid seals: quantifying fish consumption. Canadian Journal of Zoology 64: 1152–1157. https://doi.org/10.1139/z86-174

National Marine Fisheries Service. 2016. Recovery plan for the Cook Inlet Beluga Whale (*Delphinapterus leucas*). National Marine Fisheries Service, Alaska Region, Protected Resources Division, Juneau, Alaska. Accessed 6 April 2020. https://repository.library.noaa.gov/view/noaa/15979.

Nauwelaerts, S., C.D. Wilga, G.V. Lauder, and C.P. Sanford. 2008. Fluid dynamics of feeding behaviour in white-spotted bamboo sharks. Journal of Experimental

Biology 211: 3095–3102. https://doi.org/10.1242/jeb.019059

Nozères, C.A. 2006. Régime alimentaire du béluga de l'estuaire du St Laurent, Canada, tel que révélé par l'analyse des acides gras du lard. M.Sc. thesis, Laval University, Québec City, Quebec, Canada.

Parnell, A.C., R. Inger, S. Bearhop, and A.L. Jackson. 2010. Source partitioning using stable isotopes: coping with too much variation. PLoS ONE 5: e9672. https://doi.org/10.1371/journal.pone.0009672

Pierce, G.J., and P.R. Boyle. 1991. A review of methods for diet analysis in piscivorous marine mammals. Oceanography and Marine Biology 29: 409–486.

Plourde, S., P. Galbraith, V. Lesage, F. Grégoire, H. Bourdgages, J.-F. Gosselin, I. McQuinn, and M. Scarratt. 2014. Ecosystem perspective on changes and anomalies in the Gulf of St. Lawrence: a context in support of the management of the St. Lawrence beluga whale population. DFO Canadian Science Advisory Secretariat, Research Document 2013/129. Accessed 6 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/360987.pdf.

Proust, F. 1996. Composition du régime alimentaire du phoque gris (*Halichoerus grypus*) dans le Golfe du Saint-Laurent, Québec, Canada. M.Sc. thesis, Université du Québec à Rimouski, Rimouski, Quebec, Canada.

Quakenbush, L.T., R.S. Suydam, A.L. Bryan, L.F. Lowry, K.J. Frost, and B.A. Mahoney. 2015. Diet of Beluga Whales, *Delphinapterus leucas*, in Alaska from stomach contents, March-November. Marine Fisheries Review 77: 70–84. https://doi.org/10.7755/mfr.77.1.7

Richard, P.R., A.R. Martin, and J.R. Orr. 1997. Study of summer and fall movements and dive behaviour of Beaufort Sea belugas, using satellite telemetry: 1992–1995. Environmental Studies Research Fund Reports 134. Calgary, Alberta, Canada.

Salton, M., R. Kirkwood, D. Slip, and R. Harcourt. 2019. Mechanisms for sex-based segregation in foraging behaviour by a polygenous marine carnivore. Marine Ecology Progress Series 624: 213–226. https://doi.org/10.3354/meps13036

Savenkoff, C., M. Castonguay, D. Chabot, M.O. Hammill, H. Bourdages, and L. Morissette. 2007. Changes in the northern Gulf of St. Lawrence ecosystem estimated by inverse modelling: evidence of a fishery-induced regime shift? Estuarine, Coastal and Shelf Science 73: 711–724. https://doi.org/10.1016/j.ecss.2007.03.011

Scallon-Chouinard, P.-M., J.-D. Dutil, et S. Hurtubise. 2007. Liste des espèces de poissons inventoriées dans l'estuaire maritime du Saint-Laurent entre 1930 et 2005. Rapport technique canadien des sciences halieutiques et aquatiques 2719. Accessed 28 February 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/328614.pdf.

Schreer, J.F., and K.M. Kovacs. 1997. Allometry of diving capacity in air-breathing vertebrates. Canadian Journal of Zoology 75: 339–358. https://doi.org/10.1139/z97-044

Seaman, G.A., L.F. Lowry, and K.J. Frost. 1982. Foods of belukha whales (*Delphinapterus leucas*) in western Alaska. Cetology 44: 1–19.

Sergeant, D.E. 1986. Present status of white whales *Delphinapterus leucas* in the St. Lawrence Estuary. Naturaliste canadien 113: 61–81.

Smith, T.G., M.O. Hammill, and A.R. Martin. 1994. Herd composition and behaviour of Belugas, *Delphinapterus leucas*, in two Canadian Arctic estuaries. Meddelelser om Grøenland Bioscience 39: 175–184.

Smith, T.G., and A.R. Martin. 1994. Distribution and movements of Belugas, *Delphinapterus leucas*, in the Canadian High Arctic. Canadian Journal of Fisheries and Aquatic Sciences 51: 1653–1663. https://doi.org/10.1139/f94-166

Steele, D.H. 1957. The Redfish (*Sebastes marinus* L.) in the western Gulf of St. Lawrence. Journal of the Fisheries Research Board of Canada 14: 899–924. https://doi.org/10.1139/f57-038

Stenseth, N.C., G. Ottersen, J.W. Hurrell, and A. Belgrano. 2004. Marine Ecosystems and Climate Variation. Oxford University Press, Oxford, United Kingdom.

Stephens, D.W., and J.R. Krebs. 1986. Foraging Theory. Princeton University Press, Princeton, New Jersey, USA.

Stevick, P.T., J. Allen, P.J. Clapham, N. Friday, S.K. Katona, F. Larsen, J. Lien, D.K. Mattila, P.J. Palsbøll, J. Sigurjónsson, T.D. Smith, N. Øien, and P.S. Hammond. 2003. North Atlantic humpback whale abundance and rate of increase four decades after protection from whaling. Marine Ecology Progress Series 258: 263–273. https://doi.org/10.3354/meps258263

Stewart, R.E.A., S.E. Campana, C.M. Jones, and B.E. Stewart. 2006. Bomb radiocarbon dating calibrates beluga (*Delphinapterus leucas*) age estimates. Canadian Journal of Zoology 84: 1840–1852. https://doi.org/10.1111/mms.12655

Swain, D.P. 2016. Population modelling results for the assessment of Atlantic herring (*Clupea harengus*) stocks in the southern Gulf of St. Lawrence (NAFO Division 4T) to 2015. DFO Canadian Science Advisory Secretariat, Research Document 2016/061. Accessed 6 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/365970.pdf.

Szpak, P., M.-H. Julien, T.C.A. Royle, J.M. Savelle, D.Y. Yang, and M.P. Richards. 2019. Sexual differences in the foraging ecology of 19th century beluga whales (*Delphinapterus leucas*) from the Canadian High Arctic. Marine Mammal Science 2019: 1–21. https://doi.org/10.1111/mms.12655

Tinker, M.T., G. Bentall, and J.A. Estes. 2008. Food limitation leads to behavioral diversification and dietary specialization in sea otters. Proceedings of the National Academy of Science 105: 560–565. https://doi.org/10.1073/pnas.0709263105

Tollit, D.J., M.J. Stewart, P.M. Thompson, G.J. Pierce, M.B. Santos, and S. Hugues. 1997. Species and size differences in the digestion of otoliths and beaks: implications for estimates of pinniped diet composition. Canadian Journal of Fisheries and Aquatic Sciences 54: 105–119. https://doi.org/10.1139/f96-264

Vanalderweireldt, L. 2019. Le retour du bar rayé dans l'estuaire du Saint-Laurent: écoogie des jeunes stades de vie et caractérisation des habitats essentiels. Ph.D. thesis, Université du Québec à Montréal, Quebec, Canada.

Vladykov, V.D. 1944. Études sur les mammifères aqua-

tiques. III. Chasse, biologie et valeur économique du marsouin blanc ou béluga (*Delphinapterus leucas*) du fleuve et du golfe du Saint-Laurent. Département des Pêcheries, Québec City, Quebec, Canada.

Vladykov, V.D. 1946. Etudes sur les mammifères aquatiques. IV. Nourriture du marsouin blanc ou béluga (*Delphinapterus leucas*) du fleuve Saint-Laurent. Département des Pêcheries, Québec City, Quebec, Canada.

Waugh, D.A., R.S. Suydam, J.D. Ortiz, and J.G.M. Thewissen. 2018. Validation of Growth Layer Group (GLG) depositional rate using daily incremental growth lines in the dentin of beluga (*Delphinapterus leucas* (Pallas, 1776)) teeth. PLoS ONE 13: e0190498. https://doi.org/10.1371/journal.pone.0190498

Werth, A.J. 2000. Feeding in marine mammals. Pages 487–526 *in* Feeding: Form, Function and Evolution in Tetrapod Vertebrates. *Edited by* K. Schwenk. Academic Press, San Diego, California, USA.

Wilson, D.S. 1975. The adequacy of body size as a niche difference. American Naturalist: 109: 769–784. https://doi.org/10.1086/283042

Worm, B., and R.A. Myers. 2003. Meta-analysis of cod-shrimp interactions reveals top-down control in oceanic food webs. Ecology 84: 162–173. https://doi.org/10.1890/0012-9658(2003)084[0162:maocsi]2.0.co;2

Received 18 December 2019
Accepted 4 March 2020

SUPPLEMENTARY MATERIAL:

TABLE S1. Numerical abundance of fish and invertebrate species in the digestive tracts of Beluga (*Delphinapterus leucas*) collected in various regions of the St. Lawrence Estuary through Beluga carcass recovery, 1989–2019.

The Canadian Field-Naturalist

Clarifying late Holocene Coyote (*Canis latrans*)–Gray Wolf (*Canis lupus*) sympatry in the western Great Lake states

Richard P. Thiel

7167 Deuce Road, Tomah, Wisconsin 54660 USA; email: old2toes@gmail.com

Thiel, R.P. 2020. Clarifying late Holocene Coyote (*Canis latrans*)–Gray Wolf (*Canis lupus*) sympatry in the western Great Lake states. Canadian Field-Naturalist 134(1): 36–41. https://doi.org/10.22621/cfn.v134i1.2163

Abstract

North American *Canis* genetics research varies in interpreting the Pre-Columbian distribution of Coyotes (*Canis latrans*). Many studies have relied on generalized species-distribution maps and a few actually cite earlier genetics works as secondary sources. I use archaeological, paleontological, and settlement era documents to demonstrate that Coyotes were present in portions of Minnesota, Wisconsin, and Illinois thousands of years prior to European arrival. This review provides important clarification of historical Coyote distribution in the region and may have implications on the various interpretations of introgressed Coyote haplotypes present in Gray Wolves (*Canis lupus*) throughout the Great Lakes region.

Key words: Coyote (*Canis latrans*); Gray Wolf (*Canis lupus*); Great Lakes region; Coyote-wolf hybridization; Coyote-wolf sympatry; Coyote-wolf haplotypes

Introduction

Lehman *et al.* (1991) published the first study analyzing DNA of *Canis* spp. in North America, reporting Coyote (*Canis latrans*) mtDNA haplotypes in Gray Wolf (*Canis lupus*) samples from the Great Lakes region and eastern Canada. They described Pre-Columbian Coyote distribution as "confined primarily to plains and deserts " (Lehman *et al.* 1999: 105), asserting Coyotes expanded into the Great Lakes region following anthropogenic changes in Gray Wolf distribution, clearing of forests, and introduction of agriculture. They concluded that hybridization between the two species "is taking place in regions where Coyotes have only recently become abundant" (Lehman *et al.* 1999: 104).

Since Lehman *et al.* (1991) many papers have analyzed the genetics of *Canis* populations inhabiting the Great Lakes region. Most focus on introgression of Coyote genes into large wolf-like canids (hereafter referred to as wolves). At least seven subsequent genetics papers refer to Pre-Columbian Coyote distribution in vague terms (Roy *et al.* 1994; Wilson *et al.* 2000; Leonard and Wayne 2008; Koblmüller *et al.* 2009; Bozarth *et al.* 2011; vonHoldt *et al.* 2011, 2016). VonHoldt *et al.* (2011) supplied a simplified distribution map (their Figure 1) showing Coyotes as far east as Illinois and northwest Indiana. This contrasts with a vonHoldt *et al.* (2016) map (their Figure 1) showing Coyote distribution reaching east to extreme southwest Minnesota at least 560 km west of Lake Michigan. The use of generalized species-distribution maps generates inconsistencies, especially in defining boundaries, as noted by Shelton and Weckerly (2007).

A trans-Mississippi-west Pre-Columbian distribution of Coyotes has been promoted by many genetics researchers (Lehman *et al.* 1991; Roy *et al.* 1994; Wilson *et al.* 2000; Leonard and Wayne 2008; Koblmüller *et al.* 2009; Bozarth *et al.* 2011; vonHoldt *et al.* 2011, 2016). Some cite earlier genetics papers (secondary sources) in describing Coyote distributional limits (Wayne *et al.* 1992; Wilson *et al.* 2000; Leonard and Wayne 2008; Bozarth *et al.* 2011; vonHoldt *et al.* 2011).

At least 13 studies claim Coyotes expanded into the Great Lakes region, seven providing arrival dates ranging from 90 to 200 years ago (approximately 1790 to 1920; Lehman *et al.* 1991; Roy *et al.* 1994; Vilà *et al.* 1999; Wilson *et al.* 2000; Grewal *et al.* 2004; Kyle *et al.* 2006; Leonard and Wayne 2008; Koblmüller *et al.* 2009; Kays *et al.* 2010a,b; Bozarth *et al.* 2011; vonHoldt *et al.* 2011, 2016). Koblmüller *et al.* (2009: 2313) sums this view succinctly: "Over the last century, coyotes have invaded this region and hybridized with wolves".

Being certain of the temporal and spatial relationships of the two species is central to the interpretation of when, where, how, and if Coyote-wolf hybridization occurred in the Great Lakes region. Having

A contribution towards the cost of this publication has been provided by the Thomas Manning Memorial Fund of the Ottawa Field-Naturalists' Club.

performed extensive historical work on the demise of Gray Wolves in Wisconsin (Thiel 1993), I recognized the Lehman *et al.* (1991: 105) description of Coyote range limited to "plains and deserts", and many subsequent papers (Roy *et al.* 1994; Vilà *et al.* 1999; Wilson *et al.* 2000; Grewal *et al.* 2004; Kyle *et al.* 2006; Leonard and Wayne 2008; Koblmüller *et al.* 2009, Bozarth *et al.* 2011; vonHoldt *et al.* 2011, 2016) as erroneous. In order to rectify this problem, I provide documentation of Coyote presence in Wisconsin, Minnesota, and Illinois between the late Holocene and 1850.

Methods

Paleontological, archeological, and settlement era documents were searched for records of Coyotes in Illinois, Minnesota, and Wisconsin (the tri-state region) before 1920. I did not search fur trade era records, an additional source of potential information. I queried the Neotoma Paleoecology Database, (NPD, neotomadb.org—earlier version known as FAUNMAP; Graham and Lundelius 1994), a free-access paleontological database, canvasing for specimens morphologically identified as *Canis latrans* in Minnesota, Wisconsin, Illinois, Indiana, and northeastern Iowa with a timeline of 5000 to 400 years before present (YBP). Archeological periodicals from the tri-state region were also searched for documentation of Coyote and wolf remains at Native American sites. Similarly, pioneer accounts from early county histories within the tri-state region were canvassed for accounts of Coyotes and wolves. Unfortunately, many used the ambiguous term, "prairie wolf" that may refer to either *C. latrans* or *C. lupus*. Species identification was aided in narratives that described canid size (height at shoulder <55 cm, Coyote; >55 cm, wolf), weight (10–18 kg, Coyote; >25 kg, wolf; Way and Hirten 2019; R.P.T. pers. obs.), group size, existence of two varieties of wolf, and/or diet (primarily rodents and lagomorphs, Coyote; primarily ungulates, wolf). I organized spatial data to the county level in the tri-state region and noted whether the area was located in grassland or forested biomes using maps generated by Curtis (1959), Anderson (1970), and McMillan (2006). In specific areas I noted temporal aspects of sympatry. I assumed Coyote occurrences prior to the mid-1800s in Minnesota, Wisconsin, and Illinois represented breeding populations because these areas were well beyond normal dispersal distances for Coyotes (>160 km; Pyrah 1984; Geese *et al.* 1989; Harrison 1992), based on an array of genetics literature that placed the eastern continental edge of Coyote range near the Minnesota-Dakota border (Lehman *et al.* 1991; Roy *et al.* 1994; Wilson *et al.* 2000; Leonard and Wayne 2008; Koblmüller *et al.* 2009; Bozarth *et al.* 2011; vonHoldt *et al.* 2011, 2016).

Results

The Neotoma Paleoecology Database lists five archaeological sites containing Coyote remains in Illinois, two in Indiana, and one each in Minnesota, Wisconsin, and northeast Iowa, dating from 5000 to 3000 YBP to approximately the year 1650. Table 1 lists Coyotes and wolves recorded in paleontological, archeological, and settlement era documents in the tri-state region. Four archaeological documents report on sites also reported in NPD: (1) the Durst Rockshelter in Wisconsin (Theler 2000; Parmalee 1960a), and from Illinois, (2) the Havana River Group (Parmalee 1960b), (3) the Fisher site (Parmalee 1962), and (4) Riverton (Parmalee and Stephens 1972). Two additional Illinois archaeological sites contained Coyote remains 800–300 YBP (Parmalee 1960b). Three archaeological sites in Minnesota did not go beyond the genus, *Canis*, level (Anfinson 1982; Mather 2004, 2006).

Dated Coyote material extends from 5000 to 3000 YBP (Durst Rockshelter, Wisconsin) to 1910. Settler accounts document the presence of Coyotes in all three states, from 1807–1808 (Minnesota) to about 1910 (Illinois). Scientist-naturalist Increase Lapham lists a wolf from Milwaukee County and a Coyote in adjacent Racine County, Wisconsin (Lapham 1853). Even in eastern sites Coyote material dates to well before European contact (Table 1).

Overall, Coyotes and wolves were reported together in eight of 23 occurrences (35%; Table 1). Two archaeological sites reported remains of both species prior to 2000 YBP; three sites between 1000 and 400 YBP; and three sites in the 1800s. Late Holocene overlap between the two species within this region points toward a shared range through much of the region south of the northern forests (Table 1, Figure 1). Sympatric occurrences were limited to areas that favoured Coyote distribution, i.e., prairie and prairie savannah habitats (Curtis 1959; Anderson 1970; McMillan 2000), whereas wolves seemed to roam more widely throughout the region (Table 1; Thiel 1993). Significantly, three Illinois archaeological sites contained remains of both Coyote and wolf. These dated to roughly 2000 to 400 YBP. Additionally, Coyote and wolf occurrences in adjacent counties leave little doubt that Coyotes and wolves were broadly sympatric within tri-state region grasslands.

Discussion

Coyotes were present within prairie and savannah habitats from the South Dakota-Minnesota border to the Illinois-Indiana border for at least several thou-

TABLE 1. Records of Coyotes (*Canis latrans*) and wolves in Illinois, Minnesota, and Wisconsin based on paleontological, archaeological, and European settlement documents.

State	County	Approximate year	Species*	Reference
Minnesota	Blue Earth	1807–1808	C	Anonymous (1881)
	Becker	1878	C W	West and Wilcox (1907)
	Rock & Pipestone	~1885	C	Rose (1911)
Wisconsin	Sauk	5000–3000 YBP	C W	Parmalee (1960a), Theler (2000), NPD 4614
	LaFayette	1831	C	Kinzie (1975)
	La Crosse	3000 400 YBP	W	Theler (2000)
	Crawford	1000–2000 YBP	W	Theler (2000)
	Vernon	1000–400 YBP	W	Theler (2000)
	Iowa	1832	C	Draper (1903)
	Grant	1838	C W	Butterfield (1884)
	Waukesha	1839	C W	Anonymous (1880)
	Milwaukee	<1852	W	Lapham (1853)
	Racine	<1852	C	Lapham (1853)
Illinois	Crawford	2000–800 YBP	C W	Parmalee and Stephens (1972), NPD 7491
	Will	300–800	C W	Parmalee (1962)
	St. Claire	<1650	C	Parmalee (1960b)
	Pike		C W	
	Calhoun		W	
	Cook		C W	Parmalee (1962), NPD 6137
	Fulton		W	Parmalee (1962), NPD 7626
	Williamson		W	Parmalee (1962)
	Bureau	1911	C	Cory (1912)
	Edgar	1830s	C	Anonymous (1879)

*C = Coyote, W = wolf.

sand years prior to the arrival of Europeans (Table 1). Temporal sympatry in archaeological remains is difficult to ascertain, but occurrences of both species at the same sites extend from earlier than 2000 YBP to the point of European contact (approximately 1650). Temporal sympatry during the settlement period, region-wide, is unambiguous. This was captured in maps of two genetics papers (Kays *et al.* 2010b; vonHoldt *et al.* 2011), but papers by Roy *et al.* (1994), Wilson *et al.* (2000), Leonard and Wayne (2008), Koblmüller *et al.* (2009), Bozarth *et al.* (2011), and vonHoldt *et al.* (2016) stand in contrast.

Habitat destruction ($n = 10$) and deforestation ($n = 5$), along with predator control and changes in *Canis* species distributions ($n = 9$), were the most often cited bases for supposed Coyote invasion into the western Great Lakes region (Lehman *et al.* 1991; Wayne *et al.* 1992; Roy *et al.* 1994; Vilà *et al.* 1999; Wilson *et al.* 2000; Grewal *et al.* 2004; Kyle *et al.* 2006; Leonard and Wayne 2008; Koblmüller *et al.* 2009; Chambers 2010; Kays 2010a,b; Bozarth *et al.* 2011; Rutledge *et al.* 2011; vonHoldt *et al.* 2011, 2016). Although First Nations occupied the Great Lakes region greater than 12 000 YBP, and First Nations people impacted ecosystems (see Delcourt and Delcourt 2004 and Riley 2013), large scale, region-wide anthropogenic ecological disturbances did not likely begin until the period between when each state became a United States Territory and each gained statehood: Illinois, 1809 and 1818; Wisconsin, 1836 and 1848; and Minnesota, 1849 and 1858, respectively (Buley 1950; Smith 1985).

Such ecological upheavals may have occasioned Gray Wolf hybridization event(s) as their numbers declined and Coyotes increased, as suggested by many researchers (Lehman *et al.* 1991; Wayne *et al.* 1992; Roy *et al.* 1994; Vilà *et al.* 1999; Wilson *et al.* 2000; Grewal *et al.* 2004; Kyle *et al.* 2006; Leonard and Wayne 2008; Koblmüller *et al.* 2009; Chambers 2010; Kays 2010a,b; Bozarth *et al.* 2011; Rutledge *et al.* 2011; vonHoldt *et al.* 2011, 2016). However, the timing and circumstances of *Canis* population declines and changes in relative abundance of sympatric Coyote and wolf populations in the western Great Lakes states remain unclear.

Direct impacts in region-wide *Canis* populations in response to persecution and ecological upheavals

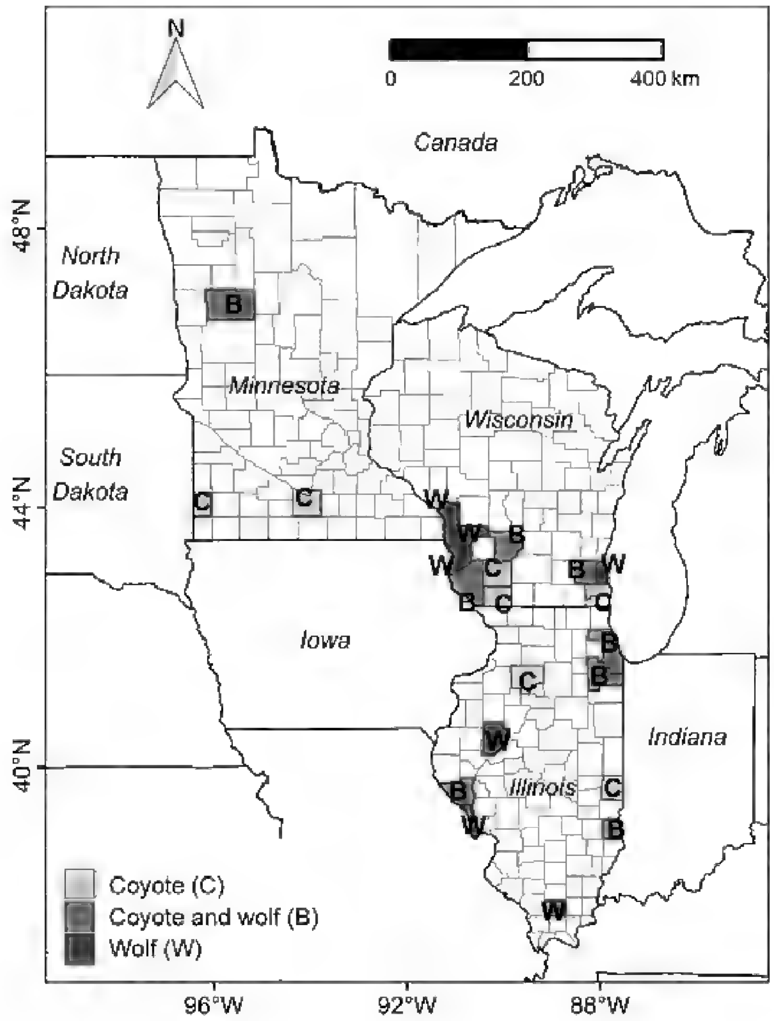


Figure 1. The spatial distribution of paleontological, archeological, and settlement era canid records. Occurrences of Coyotes (*Canis latrans*, C), wolves (W), and both Coyotes and wolves (B) are summarized by county in Minnesota, Wisconsin, and Illinois, USA.

caused by settlement likely took decades, generally moving southeast to northwest within the tri-state region. Such impacts likely did not occur during early phases of settlement (e.g., Illinois became a United States Territory in 1809; Minnesota in 1849). Wisconsin territorial bounties on both *Canis* species commenced in 1839, continuing into statehood (1848), but Gray Wolves were not extirpated from southern Wisconsin until the 1880s and northern region until the 1950s. While Coyotes likely expanded their range northwards, they were similarly persecuted throughout Wisconsin during this entire period (Thiel 1993).

Coyotes probably did not occur regularly in the mixed forests surrounding Lake Superior prior to European settlement. However, even there, periodic fire and wind-throw created large temporary openings in which dispersing Coyotes may have occasionally colonized (Schorger 1944, 1953; Loucks 1983). Coyotes expanded north into the Lake Superior basin as anthropogenic destruction of forests resulted in conversion of much of the landscape into impermanent prairie-like conditions (Schorger 1944; Allen 1979; Breitenstein and Thiel *in press*). Kays *et al.* (2010b: 249) map occurrences of museum specimens, "before 1940" but do not elaborate on the earliest dates these were collected. They demonstrate that by 1940 Coyotes were present throughout the region surrounding Lake Superior.

While not within the scope of this study, the presence of both Coyotes and wolves in three archaeological sites—one along the Illinois-Indiana border (Parmalee and Stephens 1972, NPD site 7491), one in extreme southwestern Indiana (Bergman and Peres 2014, NPD site 6600), and one in central Indiana (NPD site 6602)—extends Coyote presence and possibly the area of sympatry much further east (but see map in Kays *et al.* 2010b). These sites date to 3400 to 350 YBP. An 1830s era settler account affirms an area of sympatry along the Illinois-Indiana border confounding hypotheses for the mechanisms, places and timing of hybridization of sympatric *Canis* populations (Anonymous 1879). These sites position Coyotes much closer to eastern North America than acknowledged by current studies regarding the ancestries of Eastern Coyote, Red Wolf (*Canis rufus*), and Eastern Timber Wolf (*Canis lycaon*; Wilson *et al.* 2000; Kyle *et al.* 2006; Chambers 2010; Kays *et al.* 2010a,b; Rutledge *et al.* 2010a, 2012; Wheeldon *et al.* 2010; Bozarth *et al.* 2011; vonHoldt *et al.* 2011, 2016; Way 2013).

In-depth studies on Holocene–Anthropocene Coyote distribution, using fur-trade records and genetically testing the ancestries of paleontological and archaeological site specimens are necessary to fully understand areas of *Canis* sympatry between the Ohio River and Lakes Erie and Ontario. Archeological specimens subjected to genetic testing, such as that conducted by Rutledge *et al.* (2010b), would aid in determining areas of sympatry, temporal affinities, confirm identities of *Canis* species, and further our understanding of *Canis* haplotypes over distant time.

Acknowledgements

I extend thanks to P. DeWitt who constructed the map.

Literature Cited

Allen, D.L. 1979. The Wolves of Minong: Their Vital Role in a Wild Community. Houghton Mifflin Co., Boston, Massachusetts, USA.

Anderson, R.C. 1970. Prairies in the prairie state. Transactions of the Illinois State Academy of Science 63: 214–221.

Anfinson, S.F. 1982. Faunal remains from the Big Slough site (21MU1) and woodland cultural stability in southwestern Minnesota. Minnesota Archaeologist 41: 53–71.

Anonymous. 1879. The History of Edgar County, Illinois. Wm. Le Baron, Jr. & Sons, Chicago, Illinois, USA.

Anonymous. 1880. History of Waukesha County, Wis-

consin. Western Historical Company, Chicago, Illinois, USA.

Anonymous. 1881. History of Grant County, Wisconsin. Western Historical Company, Chicago, Illinois, USA.

Bergman, C.A., and T.M. Peres. 2014. Scientific recovery investigations at the Kramer Mound (12Sp7): prehistoric artifact assemblages, faunal and floral remains, and human osteology. Indiana Archeology 9: 13–101.

Bozarth, C., F. Hailer, L. Lockwood, C.W. Edwards, and J.E. Maldonado. 2011. Coyote colonization of northern Virginia and admixture with Great Lakes wolves. Journal of Mammalogy 92: 1070–1080. https://doi.org/10.1644/10-mamm-a-223.1

Breitenstein, J., and R.P. Thiel. *in press.* As the Twig is Bent: A Memoir. University of Wisconsin Press, Madison, Wisconsin, USA.

Buley, R.C. 1950. The Old Northwest. Indiana University Press, Volume 1, Bloomington, Indiana, USA.

Butterfield, C. 1884. History of Crawford County, Wisconsin. Union Publ. Co., Springfield, Illinois, USA.

Chambers, S.M. 2010. A perspective on the genetic composition of eastern coyotes. Northeastern Naturalist 17: 205–210. https://doi.org/10.1656/045.017.0203

Cory, C.B. 1912. The mammals of Illinois and Wisconsin. Field Museum of Natural History Publication 153. Zoological Series 11. https://doi.org/10.5962/bhl.title.15682

Curtis, J.T. 1959. The Vegetation of Wisconsin. University of Wisconsin Press, Madison, Wisconsin, USA.

Delcourt, P.A., and H.R. Delcourt. 2004. Prehistoric Native Americans and Ecological Change. Cambridge University Press, New York, New York, USA.

Draper, L.C. 1903. Wisconsin Historical Collections. Volume 1. State Historical Society of Wisconsin, Madison, Wisconsin, USA.

Geese, E.M., O.J. Rognstad, and W.R. Mytton. 1989. Population dynamics of coyotes in southeastern Colorado. Journal of Wildlife Management 53: 174–181. https://doi.org/10.2307/3801326

Graham, R.W., and E.L. Lundelius, Jr. 1994. FAUNMAP: a database documenting late Quarternary distributions of mammal species in the United States. Illinois State Museum, Scientific Papers 25: 290–690.

Grewal, S.K., P.J. Wilson, T.K. Kung, K. Shami, M.T. Theberge, J.B. Theberge, and B.N. White. 2004. A genetic assessment of the Eastern Wolf (*Canis lycaon*) in Algonquin Provincial Park. Journal of Mammalogy 85: 625–632. http://doi.org/ffxxhw

Harrison, D.J. 1992. Dispersal characteristics of juvenile coyote in Maine. Journal of Wildlife Management 56: 128–138. https://doi.org/10.2307/3808800

Kays, R., A. Curtis, and J.J. Kirchman. 2010a. Rapid adaptive evolution of northeastern coyotes via hybridization with wolves. Biology Letters. 6: 89–93. https://doi.org/10.1098/rsbl.2009.0575

Kays, R., A. Curtis, and J. J. Kirchman. 2010b. Reply to Wheeldon et al. 'Colonization history and ancestry of northeastern coyotes'. Biology Letters 6: 248–249. https://doi.org/10.1098/rsbl.2009.1022

Kinzie, J.M. 1975. Wau-bun: The Early Day in the Northwest. The National Society of Colonial Dames in Wisconsin, Portage, Wisconsin, USA.

Koblmüller, S., M. Nord, R. Wayne, and J.A. Leonard. 2009. Origin and status of the Great Lakes wolf. Molecular Ecology 18: 2313–2326. https://doi.org/10.1111/j.1365-294x.2009.04176.x

Kyle, C.J., A.R. Anderson, B.R. Patterson, P.J. Wilson, K. Shami, S.K. Grewal, and B.N. White. 2006. Genetic nature of eastern wolves: past, present and future. Conservation Genetics 7: 273–287. https://doi.org/10.1007/s10592-006-9130-0

Lapham, I.A. 1853. Fauna and flora of Wisconsin. A systematic catalogue of the animals of Wisconsin. Pages 337–370 in Transactions of the Wisconsin State Agricultural Society. Volume 2. Edited by A. Ingram. Beriah Brown, State Publisher, Madison, Wisconsin, USA.

Lehman, N., A. Eisenhawer, K. Hansen, L.D. Mech, R.O. Peterson, P. Gogan, and R. Wayne. 1991. Introgression of coyote mitochondrial DNR into sympatric North American gray wolf populations. Evolution 45: 104–119. https://doi.org/10.1111/j.1558-5646.1991.tb05270.x

Leonard, J., and R.K. Wayne. 2008. Native Great Lakes wolves were not restored. Biology Letters 4: 94–98. https://doi.org/10.1098/rsbl.2007.0354

Loucks, O.L. 1983. New light on the changing forest. Pages 17–32 *in* The Great Lakes Forest: an Environmental and Social History. *Edited by* S.L. Flader. University of Minnesota Press, Minneapolis, Minnesota, USA.

Mather, D. 2004. Zooarchaeology of the dining hall: animal bone from the original Hamline University Campus (21GD212), Red Wing, Minnesota. Minnesota Archaeologist 63: 43–55.

Mather, D. 2006. Animal remains and bone tools from the North Twin Lake site (21MH5), Mahnomen County, Minnesota. Minnesota Archaeologist 65: 93–111.

McMillan, R.B. 2006. Perspectives on the biogeography and archaeology of bison in Illinois. Pages 67–146 *in* Records of Early Bison in Illinois. *Edited by* R.B. McMillan. Illinois State Museum Scientific Papers Volume 31, Springfield, Illinois, USA.

Parmalee, P.W. 1960a. Animal remains from the Durst Rockshelter, Sauk County, Wisconsin. The Wisconsin Archaeologist 41: 11–17.

Parmalee, P.W. 1960b. Use of mammalian skulls and mandibles by Pre-historic Indians of Illinois. Transactions of the Illinois State Academy of Science 52: 85–95.

Parmalee, P.W. 1962. Faunal complex of the Fisher Site, Illinois. American Midland Naturalist 68: 399–408. https://doi.org/10.2307/2422745

Parmalee, P.W., and D. Stephens. 1972. A wolf mask and other carnivore skull artifacts from the Palestine site, Illinois. Pennsylvania Archaeologist 42: 71–74.

Pyrah, D. 1984. Social distribution and population estimates of coyotes in north-central Montana. Journal of Wildlife Management 48: 679–690. https://doi.org/10.2307/3801415

Riley, J.L. 2013. The Once and Future Great Lakes Country: an Ecological History. McGill-Queen's University Press, Kingston, Ontario, Canada.

Rose, A.P. 1911. An Illustrated History of the Counties of Rock and Pipestone, Minnesota. Northern History Publishing, LuVerne, Minnesota, USA.

Roy, M.S., E. Geffen, D. Smith, E.A. Ostrander, and

R.K. Wayne. 1994. Patterns of differentiation and hybridization in North American wolflike canids, revealed by analysis of microsatellite loci. Molecular Biology and Evolution 11: 553–570. https://doi.org/10.1093/oxfordjournals.molbev.a040137

Rutledge, L.Y., C.J. Garroway, K.M. Loveless, and B.R. Patterson. 2010a. Genetic differentiation of eastern wolves in Algonquin Park despite bridging gene flow between coyotes and grey wolves. Heredity 10: 1–12. https://doi.org/10.1038/hdy.2010.6

Rutledge, L.Y., B.N. White, J.R. Row, and B.R. Patterson. 2011. Intense harvesting of eastern wolves facilitated hybridization with coyotes. Ecology and Evolution 2:19–33. https://doi.org/10.1002/ece3.61

Rutledge, L.Y., P.J. Wilson, C.F.C. Klütsch, B.R. Patterson, and B.N. White. 2012. Conservation genomics in perspective: a holistic approach to understanding Canis evolution in North America. Biological Conservation 155: 186–192. https://doi.org/10.1016/j.biocon.2012.05.017

Schorger, A. 1944. The prairie chicken and sharp-tailed grouse in early Wisconsin. Transactions of the Wisconsin Academy of Sciences, Arts and Letters 35: 1–59.

Schorger, A. 1953. The white-tailed deer in early Wisconsin. Transactions of the Wisconsin Academy of Sciences, Arts and Letters 54: 147–179.

Shelton, S.L., and F.W. Weckerly. 2007. Inconsistencies in historical geographic range maps: the gray wolf as example. California Fish and Game 93: 224–227.

Smith, A.E. 1985. The History of Wisconsin: from Exploration to Statehood. Volume 1. Wisconsin Historical Society, Madison, Wisconsin, USA.

Theler, J.L. 2000. Animal remains from Native American archaeological sites in western Wisconsin. Transactions of the Wisconsin Academy of Sciences, Arts, and Letters 88: 121–142.

Thiel, R.P. 1993. The Timber Wolf in Wisconsin: the Death and Life of a Majestic Predator. University of Wisconsin Press, Madison, Wisconsin, USA.

Vilà, C., I.R. Amorim, J.A. Leonard, D. Posada, J. Castroviejo, F. Petrucci-Fonseca, K.A. Crandall, H. Ellegren, and R.K. Wayne. 1999. Mitchondrial DNA phylogeography and population history of the grey wolf *Canis lupus*. Molecular Ecology 8: 2089–2103. https://doi.org/10.1046/j.1365-294x.1999.00825.x

vonHoldt, B., J.A. Cahill, Z. Fan, I. Grnau, J. Robinson, J.P. Pollinger, B. Shapiro, J. Wall, and R.K. Wayne. 2016. Whole-genome sequence analysis shows that two endemic species of North American wolf are admixtures of the coyote and gray wolf. Science Advances 2: e1501714. https://doi.org/10.1126/sciadv.1501714

vonHoldt, B., J.P. Pollinger, D.A. Earl, J.C. Knowles, A.R. Boyko, H. Parker, E. Geffen, M. Pilot, W. Jedrzejewski, B. Jedrzejewski, V. Sidorovich, C. Greco, E. Randi, M. Musiani, R. Kays, C.D. Bustamonte, E.A. Ostrander, J. Novembre, and R.K. Wayne. 2011. A genome-wide perspective on the evolutionary history of enigmatic wolf-like canids. Genome Research 21: 1294–1305. https://doi.org/10.1101/gr.116301.110

Way, J.G. 2013. Taxonomic implications of morphological and genetic differences in Northeastern coyotes (coywolves) (*Canis latrans* × *C. lycaon*), western coyotes, (*C. latrans*), and eastern wolves (*C. lycaon* or *C. lupus lycaon*). Canadian Field-Naturalist 127: 1–16. https://doi.org/10.22621/cfn.v127i1.1400

Way, J.G., and J.L. Hirten. 2019. Wild *Canis* spp. of North America: a pictorial representation. Canadian Field-Naturalist 133: 295–296. https://doi.org/10.22621/cfn.v133i3.2473

Wayne, R., N. Lehman, M. Allard, and R. Honeycutt. 1992. Mitochondrial DNA variability of the gray wolf: genetic consequences of population decline and habitat fragmentation. Conservation Biology 6: 599–569. https://doi.org/10.1046/j.1523-1739.1992.06040559.x

West, J.C., and A.H. Wilcox. 1907. A Pioneer History of Becker County, Minnesota. Pioneer Press, St. Paul, Minnesota, USA.

Wheeldon, T.J., B.R. Patterson, and B.N. White. 2010. Sympatric wolf and coyote populations of the western Great Lakes region are reproductively isolated. Molecular Ecology 19: 4428–4440. https://doi.org/10.1111/j.1365-294x.2010.04818.x

Wilson, P.J., S. Grewal, I.D. Lawford, J.N.M. Heal, A.G. Granacki, D. Pennock, J.B. Theberge, M.T. Theberge, D.R. Voigt, W. Waddell, R.E. Chambers, P.C. Paquet, G. Goulet, D. Cluff, and B.N. White. 2000. DNA profiles of the eastern Canadian wolf and the red wolf provide evidence for a common evolutionary history independent of the gray wolf. Canadian Journal of Zoology 78: 2156–2166. https://doi.org/10.1139/z00-158

Received 7 December 2018
Accepted 6 April 2020

The Canadian Field-Naturalist

Note

Into the drink: observation of a novel hunting technique employed by an Eastern Gray Squirrel (*Sciurus carolinensis*)

Alex O. Sutton[1,*], Matthew Fuirst[1], and Kristen Bill[1]

[1]Department of Integrative Biology, University of Guelph, 50 Stone Road East, Guelph, Ontario N1G 2W1 Canada
[*]Corresponding author: alexosutto@gmail.com

Sutton, A.O., M. Fuirst, and K. Bill. 2020. Into the drink: observation of a novel hunting technique employed by an Eastern Gray Squirrel (*Sciurus carolinensis*). Canadian Field-Naturalist 134(1): 42–44. https://doi.org/10.22621/cfn.v134i1.2331

Abstract

Observations of typically herbivorous species have shown that animals will opportunistically eat animal tissue that is either scavenged or hunted. Squirrels from a number of genera have been observed to hunt prey and consume meat in terrestrial ecosystems. Here we provide evidence of a novel hunting strategy employed by an Eastern Gray Squirrel (*Sciurus carolinensis*), which has not previously been observed hunting aquatic prey. More rigorous observational studies are needed to determine the extent of this behaviour in Eastern Gray Squirrel populations and whether fishing is a common foraging behaviour for this species.

Key words: Eastern Gray Squirrel; fishing; foraging; hunting; predation; *Sciurus carolinensis*; swimming

A growing body of literature, including field studies and natural history notes, has confirmed that squirrels will consume vertebrate tissue, obtained through scavenging or predation (Middleton 1930; Callahan 1993; O'Donoghue 1994). Field observations and stomach content analyses have shown that squirrels will eat a wide variety of organisms, including small mammals, birds, reptiles, and amphibians (Middleton 1930; Callahan 1993). However, only a subset of these food items has been documented to be obtained through predation by a number of squirrel genera including *Sciurus*, *Tamiasciurus*, *Acthosciurus*, *Ammospermophilus*, and *Spermophilus* (summarized in Callahan 1993). Vertebrate tissue in Eastern Gray Squirrel (*Sciurus carolinensis*) diets is predominantly terrestrial in origin. However, such tissue makes up a small portion (<5%) of the overall diet (Nixon *et al.* 1968; Moller 1983). Here we document what we believe is the first observation of an Eastern Gray Squirrel hunting live fish from an aquatic environment.

At approximately 1800 on 27 September 2018, while canoeing the Speed River in Guelph, Ontario (43.543°N, 80.229°W), we encountered an Eastern Gray Squirrel perched on a large snag overhanging the water. Water levels adjacent to the snag appeared to be relatively low, and as we approached, the squirrel dove into the water. Entry into the water was head first, and its entire body went under the water's surface. This behaviour did not appear to be flight in response to our approach, because, after a few seconds, the squirrel swam back to the snag with a fish about 3–5 cm long in its mouth. It began to consume the fish before leaving the snag and retreating into denser foliage along the riverbank.

Our observation is remarkable for two reasons. No published observations of squirrels eating fish exist (although photos and unpublished anecdotes suggest that this behaviour may have been observed), and it is the first observation of a squirrel stalking, entering the water, and capturing a fish. Most observations of gray squirrels (both Eastern Gray Squirrel and Western Gray Squirrel [*Sciurus griseus*]) hunting have documented vertebrate prey as terrestrial birds and mammals (Bailey 1923; Middleton 1930; Holm 1976; Callahan 1993). Other tree and ground squirrels and chipmunks have been reported to feed on aquatic or amphibious organisms; however, in each case, the predatory event was terrestrial or the tissue was apparently acquired through scavenging (Howell 1938; Hesterberg 1940; Emmons 1980).

A contribution towards the cost of this publication has been provided by the Thomas Manning Memorial Fund of the Ottawa Field-Naturalists' Club.

In addition, there are few observations of Eastern Gray Squirrels swimming, except during mass emigration events (Schorger 1947; Larson 1962). Detailed reports by Schorger (1947) and Larson (1962) outline observations of Eastern Gray Squirrels swimming en masse and naturalists finding carcasses of drowned individuals along riverbanks and lakeshores. However, unlike other squirrel species, such as Red Squirrel (*Tamiasciurus hudsonicus*), which has been documented to swim over 2 km (Pauli 2005), Eastern Gray Squirrels are not widely reported to swim or spend significant time in the water.

The timing of our observation is also interesting as it appears not to conform to any of the three hypotheses proposed to explain predatory behaviour in squirrels (Callahan 1993). It is believed that vertebrate tissue, and in particular the nutrients obtained from it, can be an important source of energy for reproduction (Goodrum 1940; Keymer and Hime 1977). However, our observation falls outside the two peak reproductive periods for Eastern Gray Squirrel (Webley and Johnson 1983). Likewise, this observation was not an incidental kill related to either territorial defense or reproductive competition (Callahan 1993). Finally, it has been proposed that vertebrate tissue consumption by squirrels may increase seasonally to compensate for a seasonal decline in the quality of plant food (Callahan 1993). Although our observation did occur on 27 September, abundant plant resources still appeared to be available in the surrounding area. However, of the three hypotheses outlined by Callahan (1993), the latter is most likely to have influenced the fishing behaviour observed. In autumn, the diet of Eastern Gray Squirrels is composed primarily of nuts and seeds (Moller 1983); thus, it is possible that either local competition or depleted nut and seed resources may have led the observed individual to prey on alternative food sources. The fishing behaviour of the Eastern Gray Squirrel reported here might also be a learned trait unique to this population. Although the individual we observed and other members of this population likely only engage in this behaviour opportunistically, it demonstrates an unexpected behavioural flexibility in Eastern Gray Squirrel.

Author Contributions

Writing – Original Draft: A.O.S.; Writing – Review & Editing: A.O.S., M.F., and K.B.; Conceptualization – A.O.S., M.F., and K.B.; Investigation – A.O.S., M.F., and K.B.

Acknowledgements

The authors thank the Integrative Biology Graduate Student Mental Health and Wellness Committee for organizing the canoe trip that led to this observation. We also thank countless Twitter users for contributing personal anecdotes about squirrel predation and helpful links to relevant literature, which aided in the writing of this manuscript. We also thank an anonymous reviewer and Dr. Dwayne Lepitzki for providing valuable feedback that improved this manuscript.

Literature Cited

Bailey, B. 1923. Meat-eating propensities of some rodents of Minnesota. Journal of Mammalogy 4: 129. https://doi.org/10.1093/jmammal/4.2.129

Callahan, J.R. 1993. Squirrels as predators. Great Basin Naturalist 53: 137–144. Accessed 20 April 2020. https://scholarsarchive.byu.edu/gbn/vol53/iss2/5.

Emmons, L.H. 1980. Ecology and resource partitioning among nine species of African rain forest squirrels. Ecological Monographs 50: 31–54. https://doi.org/10.2307/2937245

Goodrum, P.D. 1940. A population study of the gray squirrel in Eastern Texas. Bulletin 591. Texas Agricultural Experiment Station, College Station, Texas. Accessed 14 April 2020. http://hdl.handle.net/1969.1/86173.

Hesterberg, G.A. 1940. Chipmunk eats frog. Journal of Mammalogy 31: 350–351. https://doi.org/10.1093/jmammal/31.3.350-b

Holm, R.F. 1976. Observations on a cannibalistic grey squirrel. Natural History, Miscellanea 197: 1–2.

Howell, A.H. 1938. Revision of the North American ground squirrels, with a classification of the North American Sciuridae. North American fauna 56. United States Department of Agriculture, Washington, DC, USA. https://doi.org/10.3996/nafa.56.0001

Keymer, I.F., and J.M. Hime. 1977. Nutritional osteodystrophy in a free-living red squirrel (*Sciurus vulgaris*). Veterinary Record 100(2): 31–32. https://doi.org/10.1136/vr.100.2.31

Larson, J.S. 1962. Notes on a recent squirrel emigration in New England. Journal of Mammalogy 43: 272–273. https://doi.org/10.2307/1377113

Middleton, A.D. 1930. The ecology of the American Grey Squirrel (*Sciurus carolinensis* Gmelin) in the British Isles. Proceedings of the Zoological Society of London 100: 809–843. https://doi.org/10.1111/j.1096-3642.1930.tb01000.x

Moller, H. 1983. Foods and foraging behaviour of Red (*Sciurus vulgaris*) and Grey (*Sciurus carolinensis*) squirrels. Mammal Review 13: 81–98. https://doi.org/10.1111/j.1365-2907.1983.tb00270.x

Nixon, C.M., D.M. Worley, and M.W. McClain. 1968. Food habits of squirrels in southeast Ohio. Journal of Wildlife Management 32: 294–305. https://doi.org/10.2307/3798974

O'Donoghue, M. 1994. Early survival of juvenile snowshoe hares. Ecology 75: 1582–1592. https://doi.org/10.2307/1939619

Pauli, J.N. 2005. Evidence for long-distance swimming capabilities in red squirrels, *Tamiasciurus hudsonicus*.

Northeastern Naturalist 12: 245–248. https://doi.org/10.1656/1092-6194(2005)012[0245:eflsci]2.0.co;2

Schorger, A.W. 1947. An emigration of squirrels in Wisconsin. Journal of Mammalogy 28: 401–403. https://doi.org/10.1093/jmammal/28.4.401

Webley, G.E., and E. Johnson. 1983. Reproductive physiology of the Grey Squirrel (*Sciurus carolinensis*). Mammal Review 13: 149–154. https://doi.org/10.1111/j.1365-2907.1983.tb00275.x

Received 27 August 2019
Accepted 8 April 2020

The Canadian Field-Naturalist

Eastern Coyotes (*Canis latrans* var.) consuming large ungulates in a multi-ungulate system

Juliana Balluffi-Fry[1,2,*], Liane B. Nowell[3], and Murray M. Humphries[1]

[1]McGill University, Macdonald Campus, Department of Natural Resource Sciences, 21111 Lakeshore Road, Ste. Anne de Bellevue, Quebec H9X 3V9 Canada
[2]Current address: Memorial University of Newfoundland, Department of Biology, 232 Elizabeth Avenue, St. John's, Newfoundland A1B 3X9 Canada
[3]Kenauk Institute, 1000 Chemin Kenauk, Montebello, Quebec J0V 1L0 Canada
[*]Corresponding author: jballuffifry@mun.ca

Balluffi-Fry, J., L.B. Nowell, and M.M. Humphries. 2020. Eastern Coyotes (*Canis latrans* var.) consuming large ungulates in a multi-ungulate system. Canadian Field-Naturalist 134(1): 45–51. https://doi.org/10.22621/cfn.v134i1.2149

Abstract
The feeding habits of generalist predators often vary among populations and regions. For example, Coyote (*Canis latrans*), which is a generalist predator distributed across North America, occupies a wide range of habitats and has a highly varied diet. In this observational study, we quantified the presence of mammalian prey items in 50 Eastern Coyote (*Canis latrans* var.) scats collected in late spring and summer in a private game reserve in southwestern Quebec. Nearly all scats contained hair of White-tailed Deer (*Odocoileus virginianus*; 44%), Moose (*Alces americanus*; 38%), or American Beaver (*Castor canadensis*; 38%). Although all three species are known to be consumed by coyotes, such a high proportion of Moose and White-tailed Deer simultaneously occurring in the diet of coyotes has not been previously reported. The uniqueness of the study area, with its relatively high abundance of all three prey species, may account for the uniqueness of the diet of Eastern Coyotes living there.

Key words: *Canis latrans*; Coyote; Eastern Coyote; *Alces americanus*; Moose; diet; feeding ecology; foraging ecology; feeding habits; Quebec

Introduction

Biologists often study animal feeding habits to understand a species' trophic status within its ecological community (Abramsky 1978; Chan *et al.* 2017). The feeding habits of predators are of particular interest because their regulation of prey populations can maintain ecosystem health (Fortin *et al.* 2005), but, depending on prey choice, may also affect livestock populations (Hunter and Price 1992; Reynolds and Tapper 1996; Stahler *et al.* 2006). Coyotes (*Canis latrans*) have become the apex predator in many North American regions following local eradications of Gray Wolf (*Canis lupus*) and Cougar (*Puma concolor*; Goldman 1937; Crooks and Soulé 1999; Laliberte and Ripple 2004; Roemer *et al.* 2009). This generalist predator is highly flexible and adaptable, causing its ecology to vary greatly by region (Gompper 2002). Because of the coyote's vast geographic range, combined with location-specific ecology, regional observational studies often provide new and important information about coyote behaviour and dietary niche that is relevant to our understanding of coyotes and their role in shaping trophic and community structure.

The forests of rural southern Quebec offer an interesting niche for Eastern Coyotes (*Canis latrans* var.) to exploit because this area includes the northern range of White-tailed Deer (*Odocoileus virginianus*), a common prey item, and the southern range of Moose (*Alces americanus*), which is more often associated with predation by wolves and bears (Ballard and Van Ballenberghe 1998; Snaith and Beazley 2004; Benson and Patterson 2013). Historically, Gray Wolves existed in the area, but they have been extirpated from most of the region (Peterson 1966). At present, Eastern Coyote, which is smaller than wolves but bigger than Western Coyotes (*Canis latrans*; Way 2007; Way and Hirten 2019), are the only extant canid. Eastern Coyotes are generally thought to have arisen from wolf–coyote hybridization, but the species designation of Eastern Coyote and the extent of gene flow among wolves, coyotes, and Domestic Dogs (*Canis familiaris*) remains controversial and actively studied (Way and Lynn 2016).

Studies across eastern North America show coyotes to be dietary generalists, consuming everything from Moose to small rodents, fruits, and plants (Gese and Grothe 1995; Samson and Crete 1997; Crimmins *et al.* 2012; Dowd and Gese 2012; Swingen *et al.* 2015). Using scat analysis, we describe the spring and summer vertebrate diet of Eastern Coyotes in a forested area of southwestern Quebec. We predicted that White-tailed Deer would be the most consumed vertebrate, as they are locally abundant and have been previously documented as key items in coyote diet in other parts of Ontario and Quebec with similarly high densities (Poulle *et al.* 1993; Crete *et al.* 2001; Sears *et al.* 2003).

Methods

Study area

Our study site was Kenauk Nature, a 265-km² private game reserve (Figure 1), located on the southwest border of Quebec, just north of the Ottawa River between Ottawa and Montréal. The property is crossed by a network of ~100 km of dirt roads (approximate density 0.4 km/km²). Lying in the transition zone between the St. Lawrence Lowlands and the Laurentian Mountains, the site contains primarily mixed hardwood forest, with many lakes, rivers, and wetlands. The average annual temperature is 4.8°C (SD 1.4), the average winter (November–April) temperature is −4.7°C (SD 2.6), and the average summer (May–October) temperature is 14.2°C (SD 1.2). Average total annual rainfall is 807.4 mm and total annual snowfall is 178.1 cm (Environment Canada 2017).

The reserve has a long history of forestry, and active logging still occurs. In 2012, winter aerial surveys of half the property found Moose densities of ~1.0/km²; 2014 winter surveys of the hunting zone in which the property lies (Zone 10 East) found White-tailed Deer densities of ~2.5/km² (Ministère des Forêts de la Faune et des Parcs unpubl. data). The density of Eastern Coyotes in the area is unquantified, but they are regularly observed and heard on the property. American Black Bears (*Ursus americanus*)

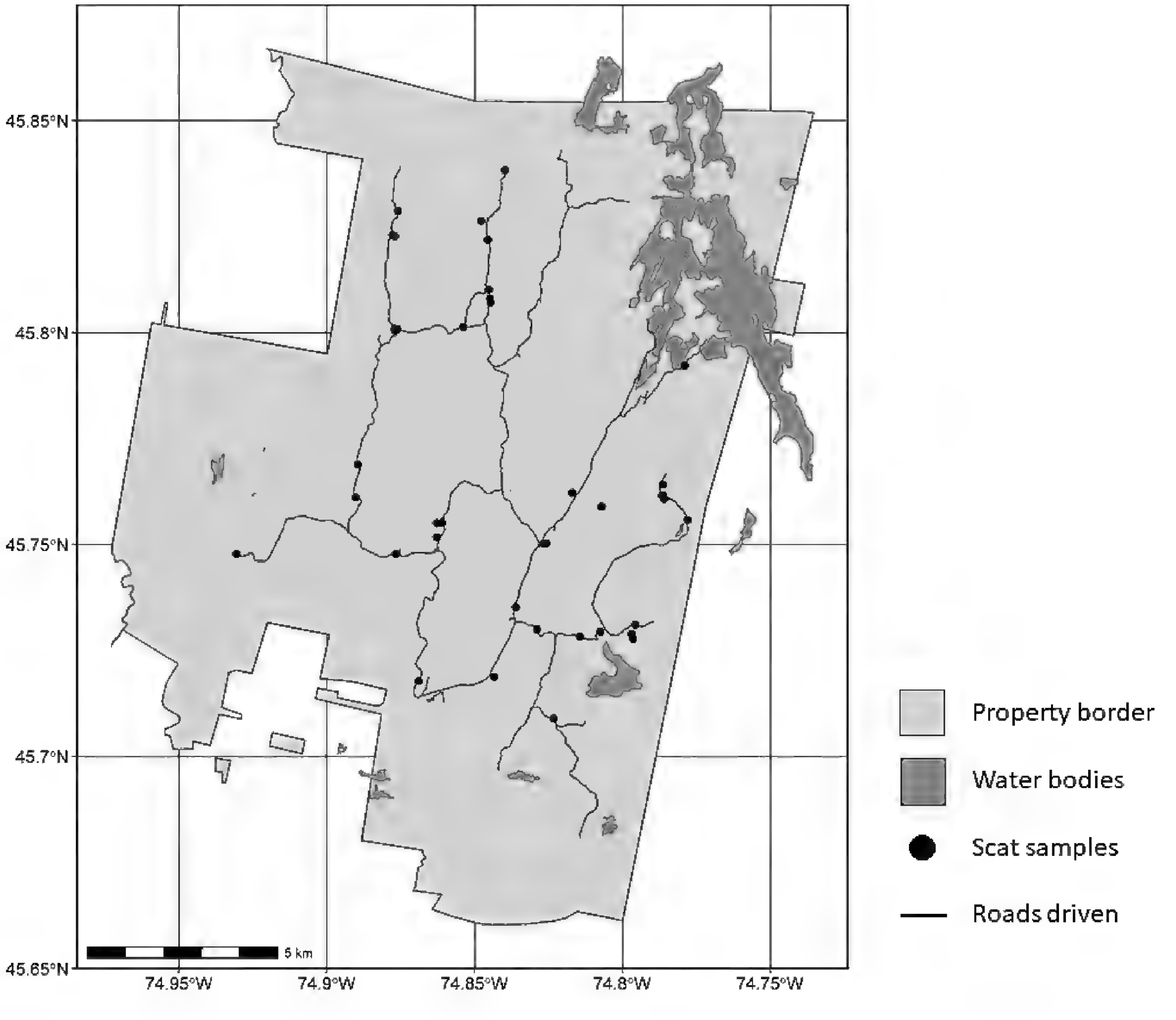


FIGURE 1. Locations of Eastern Coyote (*Canis latrans* var.) scat collected in 2016 at Kenauk Nature, Quebec, Canada, a 265-km² private game reserve just north of the Ottawa River between Ottawa and Montréal.

exist on the property, but their densities are also unknown. Canada Lynx (*Lynx canadensis*) and Bobcat (*Lynx rufus*) have not been observed, but are potential predators. In autumn, Moose are hunted from about 17 September to 20 October (females and males), and deer are hunted from about 4 to 18 November (males with ≥6 points), each with an annual limit of 10 animals; success rates are higher for Moose (L.B.N. unpubl. data).

Scat collection and predator species confirmation

Between 23 May and 27 August 2016, we collected coyote scat opportunistically on the property's unpaved road network and occasionally by hiking away from the road network (Figure 1). Coyotes have been found to use tertiary (unpaved) roads all year long, thus supporting our assumption that scat found on the road network would be relatively representative of the property's population (Bensen *et al.* 2015). We collected scats with a diameter of ≥18 mm to reduce the likelihood of collecting those of foxes or other smaller carnivores (Dumond *et al.* 2001). We sampled roads daily to once a week during the entire collection period. During roughly the first week of sampling (23–31 May), we cleared the roads of scat, retaining those that appeared fresh (digestive matrix present) and discarding those that consisted of hairs and other hard parts only, with no digestive matrix. Although the age of the first week's collected scats was unknown, we assumed they were from mid to late spring. Subsequently, collected scats were all less than one week old. We placed scats in sealable plastic bags and stored them at −20°C until processing as described in MacCracken and Hansen (1982) and Swingen *et al.* (2015).

We carried out DNA analysis on a subsample of 28 of the freshest scat (highest moisture content when collected) to confirm they were from coyotes. We thawed the scats and collected ~0.4 mL of digestive matrix into 1.5-mL microfuge tubes containing 95% ethanol. Digestive matrix subsamples were stored at −20°C until they were sent to the Canadian Centre for DNA Barcoding in Guelph, Ontario, Canada, for DNA preparation and analysis.

Similar to methods described in Moran *et al.* (2019), DNA was extracted at the Canadian Centre for DNA Barcoding directly from the homogenate we sent and amplified using vertebrate-specific primers which targetted a 185-base-pair fragment of the cytochrome c oxidase I (COI) barcode region of mtDNA. DNA was sequenced with an Ion Torrent PGM high-throughput sequencer (Thermo Fisher, Waltham, Massachusetts, USA). The raw sequence reads were demultiplexed into 30 datasets that included the 28 faecal samples and two negative controls, filtered to remove low-quality reads, and trimmed to remove primer sequences. The reads were then clustered into operational taxonomic units (OTUs) based on 98% identity and a minimum of 10 reads per OTU. Although the COI barcode region for wolves and coyotes is 95.8% identical, six diagnostic nucleotides can be used to distinguish them and confirm maternal heritage. These methods also amplified some prey DNA, but we did not use such DNA for our dietary analysis.

Dietary analysis

Scats were individually thawed, dried, and cleaned until only hard parts remained. We selected up to 10 guard hairs from across each cleaned scat for identification (Forbes and Theberge 1996 found that three hairs per scat accounted for 98.8% of prey items in wolf scat). We assessed each hair's macro-qualities (colour, length, width, texture, and shape), medulla patterns, and scale patterns of the guard hairs and compared these against known hair samples and guides (Moore *et al.* 1974). We identified Cervidae to species level (i.e., White-tailed Deer or Moose) and other prey to the family level. We distinguished among larger Rodentia species, American Beaver (*Castor canadensis*) and North American Porcupine (*Erethizon dorsatum*), but grouped small rodents into one prey group. We also recorded the presence of avian feathers found in the scats.

Results

We collected 50 scats from 23 May to 27 August, the first five of which we assumed to have been deposited in spring (April), but we do not know the precise date. Only one sample was found off roads. Although scats were never found in some sections of road, scats were distributed fairly evenly across the monitored area (Figure 1). All 28 samples sent for DNA analysis confirmed coyote maternal origin. On six occasions, we collected multiple scats at a single location and time, but in only one of these cases did scats collected together have identical dietary findings (samples 48 and 49; Table S1). The three most commonly found diet items, based on simple occurrence rate, were White-tailed Deer (0.44), Moose (0.38), and beaver (0.38; Table 1). We also observed mustelids (0.10), non-beaver rodents (0.04), and bird and feline species, which we categorized as "other" (0.04; Table 1). We did not find any lagomorph or porcupine remains in any of the scats. Although we did not distinguish between juvenile and adult ungulates, Moose hair was often thin and weak in structure, which, we speculate, could indicate that most consumed Moose were calves (Adorjan and Kolenosky 1969).

Most scats ($n = 32$) contained only a single type of hair, while the remainder had either two ($n = 16$) or three hair types ($n = 2$; Table S1). Samples never con-

TABLE 1. Diet items detected in 50 Eastern Coyote (*Canis latrans* var.) scat samples collected in 2016 at Kenauk Nature, Quebec, Canada.

Species/taxa		Samples in which diet item found (n = 50)	
Common name	Scientific name	No.	%
White-tailed Deer	*Odocoileus virginianus*	22	44
Moose	*Alces americanus*	19	38
American Beaver	*Castor canadensis*	19	38
Mustelid	Mustelidae	5	10
Non-beaver rodent	Rodentia	2	4
Other	—	2	4

tained both Moose and White-tailed Deer, and beaver hair was found both alone and paired with ungulate hair (Figure 2). Of scats containing two hair types, most consisted of beaver and an ungulate.

Discussion

White-tailed Deer, beaver, and Moose were all detected in coyote scats at similar rates, and each was detected throughout the study period from May to August (Table S1). In addition, although individual scats often contained both beaver and Moose or beaver and deer, we did not find any scats that contained both species of ungulates. A Moose or deer could feed multiple coyotes or a few coyotes over multiple days, whereas beavers are smaller and likely cannot; thus, a specific Moose or deer may be represented in

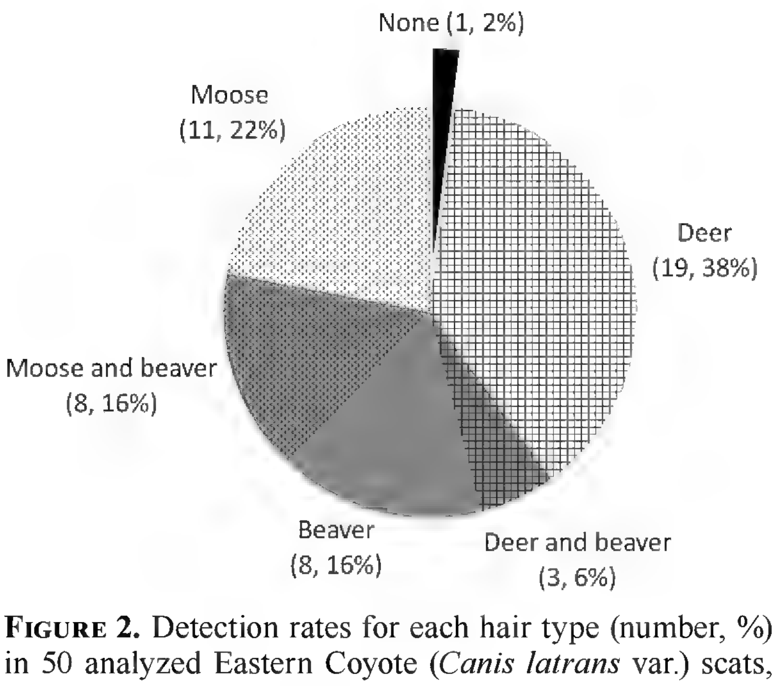


FIGURE 2. Detection rates for each hair type (number, %) in 50 analyzed Eastern Coyote (*Canis latrans* var.) scats, including the three most common items: Moose (*Alces americanus*), White-tailed Deer (*Odocoileus virginianus*), and American Beaver (*Castor canadensis*), and their combined detections. One detection equals one scat and, hence, reflects prey importance; no sample is represented by multiple categories. The category "None" represents the only sample that did not contain Moose, White-tailed Deer, or beaver, but remains of small rodents only.

multiple samples. Our results, therefore, suggest that deer, Moose, and beaver are the primary diet items of Eastern Coyotes in this reserve during the spring and summer. A study from a neighbouring area in southeastern Ontario also found deer and beaver to be common summer diet items (Sears *et al.* 2003). Although our results were in line with our prediction that White-tailed Deer would be the most common diet item, we did not expect such a high occurrence of Moose.

Many other studies from Quebec and surrounding areas have found Moose to be absent or rare in coyote diets (Richens and Hugie 1974; Messier *et al.* 1986; Poulle *et al.* 1993; Patterson *et al.* 1998; Crete *et al.* 2001; Sears *et al.* 2003). Although there are also reports of high Moose consumption and low deer consumption in Quebec and New Brunswick (Samson and Crete 1997; Dumond *et al.* 2001; Boisjoly *et al.* 2010; Power *et al.* 2019), these studies have been carried out in areas with reported high Moose densities compared with deer. A dramatic change in coyote summer diet, from White-tailed Deer as the primary ungulate consumed in 1988 to Moose by 1991, was observed in Gaspésie, Quebec (Samson and Crete 1997). During that time, deer numbers decreased greatly (based on a 76.9% decline in harvest rate), while Moose densities increased (based on a 15.1% increase in harvest rate), which the authors hypothesized as the reason for the change in diet. None of these studies show a similar occurrence rate for both Moose and deer in the diet over the same period of time, which makes our observation, even with a small sample size, notable.

Our unique observation of similarly high rates of Moose and deer consumption by Eastern Coyotes could be explained by the relatively high densities of both ungulates in our study area. Moose and White-tailed Deer ranges overlap at their southern and northern extents. The eastern area of their sympatric range grew to its current size only after land clearing in the 20th century, when deer extended their range north, causing Moose densities to decline, likely in part because of the spread of meningeal worm, *Parelaphostrongylus tenuis* (Boer 1998). Given that White-tailed Deer carry, but are not affected by this parasite, which kills Moose, it is often assumed and frequently reported that densities of these two ungulates are inversely related in eastern regions (Whitlaw and Lankester 1994). Hence, few if any coyote feeding studies have been conducted where Moose and deer are present at high abundances. We do not know the reason for our study area's high densities of both Moose and deer, but one explanation could be that the historical strip cuts and current logging practices have created ample forage. We have yet to learn the current status of *P. tenuis* in our study area.

We speculate that most of the Moose consumed were calves, based on other literature and characteristics of both Moose and White-tailed Deer, although we cannot distinguish between predation and scavenging. The vast majority of the scats collected (Table S1) were deposited during or after the window of Moose parturition in this region (Musante *et al.* 2010). Juvenile Moose are also smaller and less coordinated than adult White-tailed Deer, which Eastern Coyotes are known to predate (Poulle *et al.* 1993; Chitwood *et al.* 2014). It is commonly believed that coyotes are incapable of predating healthy, adult Moose, except during the winter months when snow can severely limit ungulate movement (Benson and Patterson 2013). We speculate that the Moose found in the first week's samples were scavenged or predated adult/yearling Moose from the spring (before the window of parturition) when the body condition of Moose is poor (Musante *et al.* 2010).

Having a better understanding of Eastern Coyote dietary patterns in the region, in particular what age classes and conditions of ungulates they consume, would help wildlife managers to quantify the influence of Eastern Coyotes on the local ungulate populations. Future work on coyote feeding habits in this reserve should include collecting more scats across multiple seasons and an age-class analysis of hairs in scats. It is possible that coyotes consume newborn Moose calves in the summer (a pulsed resource) and adults in the winter when they are made more vulnerable by snow and poor body condition (Benson and Patterson 2013). Kill site investigations, best located with global positioning system units on predators (Franke *et al.* 2006), would also help identify the species, age, and condition of larger prey and better determine whether hairs in the diet were from predation or scavenging events. In addition, sampling for *P. tenuis* should occur to learn whether a lack of *P. tenuis* promotes the high densities of Moose and White-tailed Deer or if they co-occur despite the parasite.

Author Contributions

Writing – Original draft: J.B.; Writing – Review & Editing: J.B., L.B.N., and M.M.H.; Conceptualization: J.B., L.B.N., and M.M.H.; Investigation: J.B.; Methodology: J.B.; Formal Analysis: J.B.; Funding Acquisition: L.B.N.; Resources: M.M.H.; Project Administration: L.B.N.; Supervision: M.M.H. and L.B.N.; Visualization: J.B.

Acknowledgements

This study was part of research for an honours thesis at McGill University's department of Natural Resource Sciences and was housed and supported by the Kenauk Institute. Andre Dumont from the Ministère des Forêts de la Faune et des Parcs supplied us with unpublished Moose and deer density counts for our study site description. The Canadian Centre for DNA Barcoding performed our predator DNA analysis for which we thank Sean Prosser for primary communications. We would like to thank E. Hance Ellington for critical evaluation and valuable editing of the manuscript, Christina Prokopenko for reviewing and giving commentary, Manuelle Landry-Cuerrier for assisting with project logistics, and Jessica Turgeon, Katrina Di Bacco, Celine Pichett, and Bill Nowell for scat collection help. Finally, thanks to Emina Ida, Josephine Purdy, and Daphné Bourget for assisting with the sorting of scat remains.

Literature Cited

Abramsky, Z. 1978. Small mammal community ecology. Oecologia 34: 113–123. https://doi.org/10.1007/bf00345160

Adorjan, A.S., and G.B. Kolenosky. 1969. A Manual for the Identification of Hairs of Selected Ontario Mammals. Ontario Department of Lands and Forests, Toronto, Ontario, Canada.

Ballard, W.B., and V. Van Ballenberghe. 1998. Predator/prey relationships. Pages 247–273 *in* Ecology and Management of the North American Moose. *Edited by* A.W. Franzmann and C.C. Schwartz. Wildlife Management Institute, Washington, DC, USA.

Benson, J.F., P.J. Mahoney, and B.R. Patterson. 2015. Spatiotemporal variation in selection of roads influences mortality risk for canids in an unprotected landscape. Oikos 124: 1664–1673. https://doi.org/10.1111/oik.01883

Benson, J.F., and B.R. Patterson. 2013. Moose (*Alces alces*) predation by eastern coyotes (*Canis latrans*) and eastern coyote × eastern wolf (*Canis latrans* × *Canis lycaon*) hybrids. Canadian Journal of Zoology 91: 837–841. https://doi.org/10.1139/cjz-2013-0160

Boer, A.H. 1998. Interspecific relationships. Pages 337–350 *in* Ecology and Management of the North American Moose. *Edited by* A.W. Franzmann and C.C. Schwartz. Wildlife Management Institute, Washington, DC, USA.

Boisjoly, D., J.P. Ouellet, and R. Courtois. 2010. Coyote habitat selection and management implications for the Gaspésie Caribou. Journal of Wildlife Management 74: 3–11. https://doi.org/10.2193/2008-149

Chan, K., S. Boutin, T.J. Hossie, C.J. Krebs, M. O'Donoghue, and D.L. Murray. 2017. Improving the assessment of predator functional responses by considering alternate prey and predator interactions. Ecology 98: 1787–1796. https://doi.org/10.1002/ecy.1828

Chitwood, M.C., M.A. Lashley, C.E. Moorman, and C.S. DePerno. 2014. Confirmation of coyote predation on adult female white-tailed deer in the southeastern United States. Southeastern Naturalist 13: N30–N32. https://doi.org/10.1656/058.013.0316

Crête, M., J.P. Ouellet, J.P. Tremblay, and R. Arsenault. 2001. Suitability of the forest landscape for coyotes in northeastern North America and its implications for co-

existence with other carnivores. Écoscience 8: 311–319. https://doi.org/10.1080/11956860.2001.11682658

Crimmins, S.M., J.W. Edwards, and J.M. Houben. 2012. *Canis latrans* (Coyote) habitat use and feeding habits in central West Virginia. Northeastern Naturalist 19: 411–420. https://doi.org/10.1656/045.019.0304

Crooks, K.R., and M.E. Soulé. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. Nature 400: 563–566. https://doi.org/10.1038/23028

Dowd, J.L.B., and E.M. Gese. 2012. Seasonal variation of coyote diet in northwestern Wyoming: implications for dietary overlap with Canada lynx? Northwest Science 86: 289–299. https://doi.org/10.3955/046.086.0405

Dumond, M., M.A. Villard, and E. Tremblay. 2001. Does coyote diet vary seasonally between a protected and unprotected forest landscape? Écoscience 8: 301–310. https://doi.org/10.1080/11956860.2001.11682657

Environment Canada. 2017. National climate data and information archive. Environment Canada, Ottawa, Ontario, Canada. Accessed December 2017. https://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=5612&autofwd=1.

Forbes, G.J., and J.B. Theberge. 1996. Response by wolves to prey variation in central Ontario. Canadian Journal of Zoology 74: 1511–1520. https://doi.org/10.1139/z96-165

Fortin, D., H.L. Beyer, M.S. Boyce, D.W. Smith, T. Duchesne, and J.S. Mao. 2005. Wolves influence elk movements: behavior shapes a trophic cascade in Yellowstone National Park. Ecology 86: 1320–1330. https://doi.org/10.1890/04-0953

Franke, A., T. Caelli, G. Kuzyk, and R.J. Hudson. 2006. Prediction of wolf (*Canis lupus*) kill-sites using hidden Markov models. Ecological Modelling 197: 237–246. https://doi.org/10.1016/j.ecolmodel.2006.02.043

Gese, E.M., and S. Grothe. 1995. Analysis of coyote predation on deer and elk during winter in Yellowstone National Park, Wyoming. American Midland Naturalist 133: 36–43. https://doi.org/10.2307/2426345

Goldman, E.A. 1937. The wolves of North America. Journal of Mammalogy 18: 37–45. https://doi.org/10.2307/1374306

Gompper, M.E. 2002. Top carnivores in the suburbs? Ecological and conservation issues raised by colonization of northeastern North America by coyotes. Bioscience 52: 185–190. https://doi.org/10.1641/0006-3568(2002)052[0185:tcitse]2.0.co;2

Hunter, M.D., and P.W. Price. 1992. Playing chutes and ladders: heterogeneity and the relative roles of bottom-up and top-down forces in natural communities. Ecology 73: 724–732. https://doi.org/10.2307/1940152

Laliberte, A.S., and W.J. Ripple. 2004. Range contractions of North American carnivores and ungulates. AIBS Bulletin 54: 123–138. https://doi.org/10.1641/0006-3568(2004)054[0123:rconac]2.0.co;2

MacCracken, J.G., and R.M. Hansen. 1982. Seasonal foods of coyotes in southeastern Idaho: a multivariate analysis. Great Basin Naturalist 42: 45–49.

Messier, F., C. Barrette, and J. Huot. 1986. Coyote predation on a white-tailed deer population in southern Quebec. Canadian Journal of Zoology 64: 1134–1136. https://doi.org/10.1139/z86-170

Moore, T.D., L.E. Spence, and C.E. Dugnolle. 1974. Identification of the dorsal guard hairs of some mammals of Wyoming. Bulletin 14. Wyoming Game and Fish Department, Cheyenne, Wyoming, USA.

Moran, A.J., S.W. Prosser, and J.A. Moran. 2019. DNA metabarcoding allows non-invasive identification of arthropod prey provisioned to nestling Rufous hummingbirds (*Selasphorus rufus*). PeerJ 7: e6596. https://doi.org/10.7717/peerj.6596

Musante, A.R., P.J. Pekins, and D.L. Scarpitti. 2010. Characteristics and dynamics of a regional moose *Alces alces* population in the northeastern United States. Wildlife Biology 16: 185–204. https://doi.org/10.2981/09-014

Patterson, B.R., L.K. Benjamin, and F. Messier. 1998. Prey switching and feeding habits of eastern coyotes in relation to snowshoe hare and white-tailed deer densities. Canadian Journal of Zoology 76: 1885–1897. https://doi.org/10.1139/z98-135

Peterson, R.L. 1966. The Mammals of Eastern Canada. Oxford University Press, Toronto, Ontario, Canada.

Poulle, M., M. Crête, J. Huot, et R. Lemieux. 1993. Prédation exercée par le Coyote, Canis latrans, sur le Cerf de Virginie, *Odocoileus virginianus*, dans un ravage en déclin de l'Est du Québec. Canadian Field-Naturalist 107: 177–185. Accessed 24 April 2020. https://www.biodiversitylibrary.org/page/34810311.

Power, J.W.B., M.J. Boudreau, E.M. Muntz, and S. Bondrup-Nielsen. 2019. High reliance on a diet of Moose (*Alces americanus*) by Eastern Coyotes (*Canis latrans* var.) in Cape Breton Highlands National Park, Nova Scotia, Canada. Canadian Field-Naturalist 133: 329–331. https://doi.org/10.22621/cfn.v133i4.2138

Reynolds, J.C., and S.C. Tapper. 1996. Control of mammalian predators in game management and conservation. Mammal Review 26: 127–155. https://doi.org/10.1111/j.1365-2907.1996.tb00150.x

Richens, V.B., and R.D. Hugie. 1974. Distribution, taxonomic status, and characteristics of coyotes in Maine. Journal of Wildlife Management 38: 447–454. https://doi.org/10.2307/3800875

Roemer, G.W., M.E. Gompper, and B. Van Valkenburgh. 2009. The ecological role of the mammalian mesocarnivore. BioScience 59: 165–173. https://doi.org/10.1525/bio.2009.59.2.9

Samson, C., and M. Crête. 1997. Summer food habits and population density of coyotes, *Canis latrans*, in boreal forests of southeastern Quebec. Canadian Field-Naturalist 111: 227–233. Accessed 24 April 2020. https://www.biodiversitylibrary.org/page/35481769.

Sears, H.J., J.B. Theberge, M.T. Theberge, I. Thornton, and G.D. Campbell. 2003. Landscape influence on Canis morphological and ecological variation in a coyote-wolf *C. lupus* × *latrans* hybrid zone, Southeastern Ontario. Canadian Field-Naturalist 117: 591–600. https://doi.org/10.22621/cfn.v117i4.828

Snaith, T.V., and K.F. Beazley. 2004. The distribution, status and habitat associations of moose in mainland Nova Scotia. Proceedings of the Nova Scotian Institute of Science 42: 263–317.

Stahler, D.R., D.W. Smith, and D.S. Guernsey. 2006.

Foraging and feeding ecology of the gray wolf (*Canis lupus*): lessons from Yellowstone National Park, Wyoming, USA. Journal of Nutrition 136: 1923S–1926S. https://doi.org/10.1093/jn/136.7.1923S

Swingen, M.B., C.S. DePerno, and C.E. Moorman. 2015. Seasonal coyote diet composition at a low-productivity site. Southeastern Naturalist 14: 397–404. https://doi.org/10.1656/058.014.0219

Way, J.G. 2007. A comparison of body mass of *Canis latrans* (coyotes) between eastern and western North America. Northeastern Naturalist 14: 111–124. https://doi.org/10.1656/1092-6194(2007)14[111:acobmo]2.0.co;2

Way, J.G., and J.L. Hirten. 2019. Wild *Canis* spp. of North America: a pictorial representation. Canadian Field-Naturalist 133: 295–296. https://doi.org/10.22621/cfn.v133i3.2473

Way, J.G., and W.S. Lynn. 2016. Northeastern coyote/coywolf taxonomy and admixture: a meta-analysis. Canid Biology & Conservation 19: 1–7.

Whitlaw, H.A., and M.W. Lankester. 1994. The co-occurrence of moose, white-tailed deer, and *Parelaphostrongylus tenuis* in Ontario. Canadian Journal of Zoology 72: 819–825. https://doi.org/10.1139/z94-111

Received 29 October 2018
Accepted 10 April 2020

SUPPLEMENTARY MATERIAL:

Table S1. Location and prey content of 50 Eastern Coyote (*Canis latrans* var.) scat samples collected in 2016 at Kenauk Nature, Quebec, Canada.

The Canadian Field-Naturalist

Note

Sphex ichneumoneus and *Sphex pensylvanicus* (Hymenoptera: Sphecidae) in Atlantic Canada: evidence of recent range expansion into the region

Jake H. Lewis

Canadian Museum of Nature, 1740 Pink Road, Gatineau, Quebec J9J 3N7 Canada; New Brunswick Museum, 277 Douglas Avenue, Saint John, New Brunswick E2K 1E5 Canada; email: jlewis3@unb.ca

Lewis, J.H. 2020. *Sphex ichneumoneus* and *Sphex pensylvanicus* (Hymenoptera: Sphecidae) in Atlantic Canada: evidence of recent range expansion into the region. Canadian Field-Naturalist 134(1): 52–55. https://doi.org/10.22621/cfn.v134i1.2413

Abstract

The detection of range shifts is an important part of tracking species' responses to climate warming and anthropogenic disturbance. Here, arguments in support of such change-induced expansion of the thread-waisted wasps, *Sphex pensylvanicus* and *Sphex ichneumoneus* (Hymenoptera: Sphecidae), into Atlantic Canada are made on the basis of collections in southwestern New Brunswick. Despite their large size, bold colouration, and active presence on wildflowers in open areas, no previous records for either species exist from Atlantic Canada. Increases in mean annual temperature, as well as increases in the abundance, regional diversity, and uniformity in the ranges of katydids (Tettigoniidae), the preferred nest provision for both *Sphex* species, may be promoting northward colonization by *Sphex* wasps.

Key words: Range expansion; *Sphex*; climate change; anthropogenic disturbance; Hymenoptera; Sphecidae; wasp; thread-waisted wasp; climate warming; geographic range

Climate change and anthropogenic disturbance are significantly altering the ranges of insects on a global scale (Parmesan *et al.* 1999; Hickling *et al.* 2005; Schowalter 2012). Although studies of the northeastern North American fauna have identified range shifts in charismatic taxa such as Lepidoptera and Odonata (Rodenhouse *et al.* 2009; Catling 2016; McAlpine *et al.* 2017), disease vectors (Rochlin *et al.* 2016), pollinators (mostly bees and, to a lesser extent, flies; Deans *et al.* 2007; Harrison *et al.* 2019), and other economically important groups (Dukes *et al.* 2009), reports of climate change or anthropogenic driven shifts in the distributional ranges of wasps are generally lacking (Sánchez-Bayo and Wyckhuys 2019). The principal reason for the shortage of wasp-based studies is almost certainly the scarcity of accessible taxonomic resources for many taxa; indeed, wasps are one of the least-known groups taxonomically and are possibly also the most diverse animal group on the planet (Forbes *et al.* 2018).

The relative ignorance of wasps in many regions is problematic for biodiversity conservation, as Hymenoptera appear to be experiencing some of the greatest declines among the terrestrial orders of insects (Sánchez-Bayo and Wyckhuys 2019). Particularly for highly host-specific parasitoid wasps, changes in climate patterns can be devastating when the phenological synchrony of wasp and host(s) is compromised (Stireman *et al.* 2005; Hance *et al.* 2007; Kharouba *et al.* 2018). In addition, changes in the species composition and diversity of local wasp communities can occur over relatively short periods. Using morphology and DNA barcoding, Fernandez-Triana *et al.* (2011) found that the community structure of parasitoid wasps in northern Manitoba has changed significantly over the last 70 years and is likely linked to climate warming.

Here, the apparent recent range expansion of the thread-waisted wasps (Hymenoptera: Sphecidae), *Sphex ichneumoneus* (Linnaeus, 1758) and *Sphex pensylvanicus* Linnaeus, 1763, into Atlantic Canada is reported for the first time on the basis of specimens recently collected in southwestern New Brunswick. All specimens were collected by aerial net or by hand during general insect surveys and are deposited in the New Brunswick Museum insect collection.

A contribution towards the cost of this publication has been provided by the Thomas Manning Memorial Fund of the Ottawa Field-Naturalists' Club.

The Sphecidae are a charismatic group of largely solitary wasps that dig burrows (most Sphecinae and Ammophilinae) or build clay nests (Sceliphrinae), which they provision with insect prey (Matthews 1991; Finnamore and Michener 1993). Both *S. ichneumoneus* and *S. pensylvanicus* have been previously recorded in Quebec and Ontario (Buck 2003) and across much of the United States (Bohart and Menke 1963). Detailed studies on the behaviour of northern populations of *S. ichneumoneus* have revealed that adults live approximately six weeks, are active from mid-July to mid-September, are most active at temperatures above 26°C and inactive at temperatures below 18°C, nest in open areas with relatively little ground cover and in clay or sandy soil, and, as nectarivores, build their nests in the vicinity of wildflowers (Brockman 1976, 1979; Brockman and Dawkins 1979). *Sphex pensylvanicus* has similar seasonality, temperature preferences, and habitat preferences (Frisch 1938; Rau 1944; Kurczewski 1997).

Both species are large (19–28 mm), strikingly patterned, and often active on wildflowers in open, semi-forested areas; if present, they would likely not go undetected. Despite this, there are no specimens of either species from Atlantic Canada in the insect collections of the New Brunswick Museum (NBM), Nova Scotia Museum (NSM), University of Guelph (DEBU), Royal Alberta Museum (RAM), or in the Canadian National Collection of Insects, Arachnids and Nematodes (CNC), and no published records for Atlantic Canada prior to those reported here. Although not conclusive evidence, this is notable and suggests that a fairly recent range expansion of *Sphex* into the region may have occurred.

In addition, the *Sphex* species mentioned here are katydid specialists and provision their nests primarily with various members of the Tettigoniidae (Bohart and Menke 1963; Brockman 1985). Based on published reports, the orthopteran species used by *S. pensylvanicus* and *S. ichneumoneus* appear to differ somewhat: the former preys on larger katydids such as Fork-tailed Bush Katydid (*Scudderia furcata* Brunner, 1878; Rau 1944), Northern Bush Katydid (*Scudderia septentrionalis* (Serville 1839); Kurczewski 1997), and Greater Angle-wing Katydid (*Microcentrum rhombifolium* (Saussure, 1859); Frisch 1938); the latter preys on a wider variety of orthopterans (Brockman 1985) including various *Scudderia* spp., *Neoconocephalus* spp., *Conocephalus* spp., *Orchelimum* spp., and, to a somewhat lesser extent, Black-horned Tree Cricket (*Oecanthus nigricornis* F. Walker, 1869). As both *Sphex* species show an obvious preference for katydids as nest provisions, any increases in the abundance, regional diversity, or uniformity in the ranges of katydids should promote further colonization by these wasps.

All members of the Tettigoniidae known to occur in Maritime Canada prefer open areas, such as old field habitat, forest clearings and trails, and roadside margins (Vickery and Kevan 1985). Given that forestry, agriculture, and industry have transformed Atlantic Canada into a much patchier, heterogeneous landscape over the last five centuries (Loo *et al.* 2010), an increase in abundance and geographic uniformity of katydids in the region during this period seems likely. There is also evidence of recent expansion of some orthopteran species used by *Sphex* in the region (McAlpine and Ogden 2012; Klymko *et al.* 2018; Lewis and McAlpine 2018), such as native Sword-bearing Conehead Katydid (*Neoconocephalus ensiger* (Harris, 1841)), *S. septentrionalis*, *O. nigricornis*, and the European introduction Roesel's Shield-backed Katydid (*Metrioptera roeselii* (Hagenbach, 1822)). As climate warming continues, further increases in the abundance and range of orthopterans in the region can be expected (Scudder and Vickery 2010).

Many climate warming studies have used historical data to examine changes in the phenology of insects, particularly in northern regions. Climate warming in northern areas will allow some species to be active for longer periods (Levy *et al.* 2016). Altermatt (2009) found that, even since 1980, the warmer climate has allowed some European butterflies and moths to increase the number of generations completed within a season. This may, however, be harmful for species that produce an additional generation but encounter a lack of available host plants (Altermatt 2009) or those that fail to enter diapause on time (Buckley *et al.* 2017). As the northern populations of *S. ichneumoneus* (and presumably also *S. pensylvanicus*) are univoltine (Brockman 1985), any increase in temperature will likely be beneficial and may allow these wasps to be active longer each day and later in the season when their preferred katydid nest provisions are mature and most active.

Voucher specimens

Sphex ichneumoneus (Linnaeus, 1758)—CANADA, NEW BRUNSWICK: Saint John County: Black Beach, end of Lighthouse Road, 7.5 km southwest of Lorneville, 45.144285°N, 66.236958°W, 15 September 2017, J.H. Lewis, one dead male taken from spider web on *Solidago* sp. in coastal old field habitat (NBM-068251), orthopterans *Oecanthus nigricornis*, Slender Meadow Katydid (*Conocephalus fasciatus* (De Geer, 1773)), and Broad-winged Bush Katydid (*Scudderia pistillata* Brunner, 1878) also collected.

Sphex pensylvanicus Linnaeus, 1763—CANADA, NEW BRUNSWICK: Kings County: along Nerepis River, near intersection of Brittain Road and McKenzie Road, 45.390972°N, 66.285265°W, 15 August 2015,

J.H. Lewis, along Silver Maple (*Acer saccharinum* L.) dominated floodplain forest in wildflower rich clearing, two males taken from Queen-of-the-Meadow (*Filipendula ulmaria* (L.) Maximowicz) (NBM-052358; NBM-052382), orthopterans *Conocephalus fasciatus* and *Scudderia pistillata* also collected; Charlotte County: along Highway 1, between Oak Bay and St. Stephen, 45.219586°N, 67.232816°W, 25 September 2017, J.H. Lewis, two females taken along wildflower rich trail near highway (NBM-068247), orthopterans *Scudderia septentrionalis* and *Oecanthus nigricornis* also collected.

Acknowledgements

I thank Dr. Stephen Clayden (New Brunswick Museum) for confirming the identities of wildflowers referenced in the collection notes. Dr. Andrew Bennett (Canadian National Collection of Insects, Arachnids and Nematodes), Dr. Steven Paiero (University of Guelph), Katherine Ogden (Nova Scotia Museum), and Dr. Matthias Buck (Royal Alberta Museum) confirmed the lack of *Sphex* wasp specimens from Atlantic Canada in their respective collections. I also thank Dr. Robert Anderson (Canadian Museum of Nature) and Dr. Donald McAlpine (New Brunswick Museum) for their critical reviews of the manuscript.

Literature Cited

Altermatt, F. 2009. Climatic warming increases voltinism in European butterflies and moths. Proceedings of the Royal Society B: Biological Sciences 277: 1281–1287. https://doi.org/10.1098/rspb.2009.1910

Bohart, R.M., and A.S. Menke. 1963. A reclassification of the Sphecinae: with a revision of the Nearctic species of the tribes Sceliphronini and Sphecini (Hymenoptera, Sphecidae). University of California Publications in Entomology 30. University of California, Berkley, California, USA.

Brockman, H.J. 1976. The control of nesting behavior in the great golden digger wasp, *Sphex ichneumoneus* L. (Sphecidae). Ph.D. thesis, University of Wisconsin, Madison, Wisconsin, USA.

Brockman, H.J. 1979. Nest-site selection in the great golden digger-wasp, *Sphex ichneumoneus* L. (Sphecidae). Ecological Entomology 4: 211–224. https://doi.org/10.1111/j.1365-2311.1979.tb00578.x

Brockman, H.J. 1985. Provisioning behavior of the Great Golden Digger Wasp, *Sphex ichneumoneus* (L.) (Sphecidae). Journal of the Kansas Entomological Society 58: 631–655.

Brockman, H.J., and R. Dawkins. 1979. Joint nesting in a digger wasp as an evolutionarily stable preadaptation to social life. Behavior 71: 203–245.

Buck, M. 2003. An annotated checklist of the spheciform wasps of Ontario (Hymenoptera: Ampulicidae, Sphecidae and Crabronidae). Journal of the Entomological Society of Ontario 134: 19–84.

Buckley, L.B. A.J. Arakaki, A.F. Cannistra, H.M. Kharouba, and J.G. Kingsolver. 2017. Insect development, thermal plasticity and fitness implications in changing, seasonal environments. Integrative and Comparative Biology 57: 988–998. https://doi.org/10.1093/icb/icx032

Catling, P.M. 2016. Climate warming as an explanation for the recent northward range extension of two dragonflies, *Pachydiplax longipennis* and *Perithemis tenera*, into the Ottawa Valley, eastern Ontario. Canadian Field-Naturalist 130: 122–132. https://doi.org/10.22621/cfn.v130i2.1846

Deans, A.M., S.M. Smith, J.R. Malcolm, W.J. Crins, and M.I. Bellocq. 2007. Hoverfly (Syrphidae) communities respond to varying structural retention after harvesting in Canadian peatland black spruce forests. Environmental Entomology 36: 308–318. https://doi.org/10.1093/ee/36.2.308

Dukes J.S., J. Pontius, D. Orwig, J.R. Garnas, V.L. Rodgers, N. Brazee, B. Cooke, K.A. Theoharides, E.E. Stange, R. Harrington, J. Ehrenfeld, J. Gurevitch, M. Lerdau, K. Stinson, R. Wick, and M. Ayres. 2009. Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: what can we predict? Canadian Journal of Forest Research 39: 231–248. https://doi.org/10.1139/X08-171

Fernandez-Triana, J., M.A. Smith, C. Boudreault, H. Goulet, P.D.N. Hebert, A.C. Smith, and R. Roughley. 2011. A poorly known high-latitude parasitoid wasp community: unexpected diversity and dramatic changes through time. PLoS ONE 6: e23719. https://doi.org/10.1371/journal.pone.0023719

Finnamore, A.T., and C.D. Michener. 1993. Chapter 9 – Superfamily Apoidea. Pages 279–357 *in* Hymenoptera of the World: an Identification Guide to Families. Publication 1894/E. *Edited by* H. Goulet and J.T. Huber. Research Branch, Agriculture Canada, Ottawa, Ontario, Canada.

Forbes, A.A., R.K. Bagley, M.A. Beer, A.C. Hippee, and H.A. Widmayer. 2018. Quantifying the unquantifiable: why Hymenoptera, not Coleoptera, is the most speciose animal order. BMC Ecology 18: 21. https://doi.org/10.1186/s12898-018-0176-x

Frisch, J.A. 1938. The life-history and habits of the digger-wasp *Ammobia pennsylvanica* (Linn.). American Midland Naturalist 19: 673–677. http://doi.org/10.2307/2420481

Hance, T., J. van Baaren, P. Vernon, and G. Boivin. 2007. Impact of extreme temperatures on parasitoids in a climate change perspective. Annual Review of Entomology 52: 107–126. https://doi.org/10.1146/annurev.ento.52.110405.091333

Harrison, T., J. Gibbs, and R. Winfree. 2019. Anthropogenic landscapes support fewer rare bee species. Landscape Ecology 34: 967–978. https://doi.org/10.1007/s10980-017-0592-x

Hickling, R., D.B. Roy, J.K. Hill, and C.D. Thomas. 2005. A northward shift of range margins in British Odonata. Global Change Biology 11: 502–506. https://doi.org/10.1111/j.1365-2486.2005.00904.x

Kharouba, H.M., J. Ehrlén, A. Gelman, K. Bolmgren, J.M. Allen, S.E. Travers, and E.M. Wolkovich. 2018. Global shifts in the phenological synchrony of species interactions over recent decades. Proceedings of the National Academy of Sciences of the United States of America 115: 5211–5216. https://doi.org/10.1073/pnas.1714511115

Klymko, J., P. Catling, J.B. Ogden, R.W. Harding, D.F. McAlpine, S.L. Robinson, D.A. Doucet, and C.I.G. Adam. 2018. Orthoptera and allies in the Maritime provinces, Canada: new records and updated provincial checklists. Canadian Field-Naturalist 132: 319–329. https://doi.org/10.22621/cfn.v132i4.1984

Kurczewski, F.E. 1997. Activity patterns in a nesting aggregation of *Sphex pensylvanicus* L. (Hymenoptera: Sphecidae). Journal of Hymenoptera Research 6: 231–242.

Levy, O., L.B. Buckley, T.H. Keitt, and M.J. Angilletta, Jr. 2016. Ontogeny constrains phenology: opportunities for activity and reproduction interact to dictate potential phenologies in a changing climate. Ecology Letters 19: 620–628. https://doi.org/10.1111/ele.12595

Lewis, J.H., and D.F. McAlpine. 2018. *Scudderia fasciata* and *Scudderia septentrionalis* (Orthoptera: Tettigoniidae) from the Maritime Provinces of Canada, with additional notes on the Tettigoniidae of New Brunswick. Journal of the Acadian Entomological Society 14: 17–21.

Loo, J., L. Cwynar, B. Freedman, and N. Ives. 2010. Changing forest landscapes in the Atlantic Maritime Ecozone. Pages 35–42 *in* Assessment of Species Diversity in the Atlantic Maritime Ecozone. *Edited by* D.F. McAlpine and I.M. Smith. NRC Research Press, Ottawa, Ontario, Canada.

Matthews, R.W. 1991. Evolution of social behavior in sphecid wasps. Pages 570–602 *in* The Social Biology of Wasps. *Edited by* K.G. Ross and R.W. Matthews. Cornell University Press, Ithaca, New York, USA.

McAlpine, D.F., H.S. Makepeace, D.L. Sabine, P.M. Brunelle, J. Bell, and G. Taylor. 2017. First occurrence of *Enallagma pictum* (Scarlet Bluet) (Odonata: Coenagrionidae) in Canada and additional records of *Celithemis martha* (Martha's Pennant) (Odonata: Libellulidae) in New Brunswick: possible climate-change induced range extensions of Atlantic Coastal Plain Odonata. Journal of the Acadian Entomological Society 13: 49–53.

McAlpine, D.F., and J.B. Ogden. 2012. New and noteworthy records of Orthoptera from Maritime Canada. Journal of the Acadian Entomological Society 8: 43–47.

Parmesan, C., N. Ryrholm, C. Stefanescu, J.K. Hill, C.D. Thomas, H. Descimon, B. Huntley, L. Kaila, J. Kullberg, T. Tammaru, W.J. Tennent, J.A. Thomas, and M. Warren. 1999. Poleward shifts in geographical ranges of butterfly species associated with regional warming. Nature 399: 579–583. https://doi.org/10.1038/21181

Rau, P. 1944. The nesting habits of the wasp, *Chlorion* (*Ammobia*) *pennsylvanicum* L. Annals of the Entomological Society of America 37: 439–440. https://doi.org/10.1093/aesa/37.4.439

Rochlin, I., A. Faraji, D.V. Ninivaggi, C.M. Barker, and A.M. Kilpatrick. 2016. Anthropogenic impacts on mosquito populations in North America over the past century. Nature Communications 7: 13604. https://doi.org/10.1038/ncomms13604

Rodenhouse, N.L., L.M. Christenson, D. Parry, and L.E. Green. 2009. Climate change effects on native fauna of northeastern forests. Canadian Journal of Forest Research 39: 249–263. https://doi.org/10.1139/x08-160

Sánchez-Bayo, F., and K.A.G. Wyckhuys. 2019. Worldwide decline of the entomofauna: a review of its drivers. Biological Conservation 232: 8–27. https://doi.org/10.1016/j.biocon.2019.01.020

Schowalter, T.D. 2012. Insect responses to major landscape-level disturbance. Annual Review of Entomology 57: 1–20. https://doiorg/10.1146/annurev-ento-120710-100610

Scudder, G.E., and V.R. Vickery. 2010. Grasshoppers (Orthoptera) and allied insects of the Atlantic Maritime Ecozone. Pages 371–379 *in* Assessment of Species Diversity in the Atlantic Maritime Ecozone. *Edited by* D.F. McAlpine and I.M. Smith. NRC Research Press, Ottawa, Ontario, Canada.

Stireman, III, J.O., L.A. Dyer, D.H. Janzen, M.S. Singer, J.T. Lill, R.J. Marquis, R.E. Ricklefs, G.L. Gentry, W. Hallwachs, P.D. Coley, J.A. Barone, H.F. Greeney, H. Connahs, P. Barbosa, H.C. Morais, and I.R. Diniz. 2005. Climatic unpredictability and parasitism of caterpillars: implications of global warming. Proceedings of the National Academy of Sciences of the United States of America 102: 17384–17387. https://doi.org/10.1073/pnas.0508839102

Vickery, V.R., and D.K.M. Kevan. 1985. The Insects and Arachnids of Canada, Part 14. The Grasshoppers, Crickets, and Related Insects of Canada and Adjacent Regions. Ulonata: Dermaptera, Cheleutoptera, Notoptera, Dictuoptera, Grylloptera, and Orthoptera. Publication 1777. Research Branch, Agriculture Canada, Ottawa, Ontario, Canada.

Received 2 December 2019
Accepted 22 April 2020

The Canadian Field-Naturalist

Note

Passive transport of Eastern Elliptio (*Elliptio complanata*) by freshwater turtles in New England

Michael T. Jones[1,2,*], Lisabeth L. Willey[3,4], Derek T. Yorks[5], Peter D. Hazelton[1], and Steve L. Johnson[6]

[1]Natural Heritage and Endangered Species Program, Division of Fisheries and Wildlife, Westborough, Massachusetts 01581 USA
[2]Department of Environmental Conservation, University of Massachusetts, Amherst, Massachusetts 01003 USA
[3]Department of Environmental Studies, Antioch University New England, Keene, New Hampshire 03431 USA
[4]American Turtle Observatory, New Salem, Massachusetts 01355 USA
[5]Maine Department of Inland Fisheries and Wildlife, 284 State Street, Augusta, Maine 04330 USA
[6]SWCA Environmental, 15 Research Drive, Amherst, Massachusetts 01002 USA
[*]Corresponding author: michael.t.jones@mass.gov

Jones, M.T., L.L. Willey, D.T. Yorks, P.D. Hazelton, and S.L. Johnson. 2020. Passive transport of Eastern Elliptio (*Elliptio complanata*) by freshwater turtles in New England. Canadian Field-Naturalist 134(1): 56–59. https://doi.org/10.22621/cfn.v134i1.2379

Abstract
Dispersal of freshwater mussels (order Unionida) is primarily as glochidia on the fins and gills of host fish. Adult mussels are more sessile, generally moving short distances (<2 m/week) along lake and river beds. Between 2007 and 2016, we observed seven instances of adult Eastern Elliptio (*Elliptio complanata*) and one instance of a fingernail clam (*Sphaerium* sp.) attached to the feet of freshwater turtles in streams and ponds of New England, United States. Observations included five instances of mussels attached to Wood Turtles (*Glyptemys insculpta*) in Maine and Massachusetts, one instance of a mussel attached to the fingernail of an Eastern Painted Turtle (*Chrysemys picta*) in Massachusetts, one instance of a mussel attached to a Snapping Turtle (*Chelydra serpentina*) in Massachusetts, and one instance of a fingernail clam attached to the fingernail of an Eastern Painted Turtle in Massachusetts. We suggest that Eastern Elliptio may be susceptible to transport by freshwater turtles foraging in mussel beds and that transport of adult mussels by freshwater turtles could result in otherwise atypical long-distance, upstream, or overland dispersal between waterbodies.

Key words: Eastern Elliptio; *Elliptio complanata*; freshwater mussel; Wood Turtle; *Glyptemys insculpta*; Eastern Painted Turtle; *Chrysemys picta*; Snapping Turtle; *Chelydra serpentina*; fingernail clam; Sphaeriidae; *Sphaerium* sp.; dispersal

Eastern Elliptio (*Elliptio complanata*), which is among the more abundant and widespread freshwater mussels (Unionida) of northeastern North America, is a generalist species reportedly capable of parasitizing over 20 fish species from nine families (reviewed by Lellis *et al.* 2013). Dispersal of freshwater mussels occurs primarily through glochidial (i.e., larval) attachment and transport on host fishes (Balfour and Smock 1995; Terui and Miyazaki 2015). Movement of adult freshwater mussels via crawling may be associated with spawning aggregations (Amyot and Downing 1997), changes in water levels (Newton *et al.* 2015), or other environmental changes (Schwalb and Pusch 2007). However, movements of adult mussels, including Eastern Elliptio, are generally short (<2 m/week) and are not thought to be of significant value for long-distance dispersal (Balfour and Smock 1995; Schwalb and Pusch 2007; Terui and Miyazaki 2015). Here, we provide evidence of three species of freshwater turtle passively transporting adult Eastern Elliptio attached to their claws or feet. We also present one occurrence of a turtle transporting a fingernail clam (*Sphaerium* sp.), adding to other reports of this phenomenon on amphibians (Engel *et al.* 2008; Wood *et al.* 2008; Kappes and Haase 2012).

We observed seven instances of Eastern Elliptio, and one instance of a fingernail clam (*Sphaerium* sp.) attached to the claws and feet of wild, freshwater turtles. Five of these observations were made during Wood Turtle (*Glyptemys insculpta*) studies involv-

ing more than 15000 visual and nonvisual detections of 1765 Wood Turtles (Jones 2009; Jones *et al.* 2018). On 4 October 2007, we radio-located adult male Wood Turtle #333 (straight carapace length [SCL] 184.4 mm; mass 912 g) in Franklin County, Massachusetts. An adult Eastern Elliptio was firmly attached to the turtle's hind right foot. At the time of observation, the turtle was walking on the river bottom. On 12 September 2013, we located male Wood Turtle #98-13 (SCL 200.0 mm; mass 1181 g) during a standardized visual survey (Jones *et al.* 2018) in Somerset County, Maine. The turtle was submerged on the stream bottom and an adult Eastern Elliptio was firmly attached to the turtle's hind foot. On 13 September 2013 during a timed survey in Somerset County, we located Wood Turtle male #126 (SCL 201.0 mm; mass 1271 g) walking quickly upstream on the river bottom. An adult Eastern Elliptio was attached firmly to a fingernail on his hind left foot (Figure 1a). On 13 October 2013, we again located male #126, the same Wood Turtle observed on 13 September, during a timed survey. The turtle was 444 m upstream of his earlier location on 13 September and, again, had an Eastern Elliptio firmly attached, this time to his front left foot (Figure 1b). We determined from photographs that the mussel was a different individual. At the time of capture, the turtle was submerged on the river bottom. In none of the preceding cases did the mussel appear to impede movement of the turtle. On 19 September 2015, during another standardized Wood Turtle survey in Somerset County, we located an adult female Wood Turtle (#452) basking on a clay riverbank with an adult Eastern Elliptio attached to her front foot (Figure 1c).

We observed similar phenomena with Eastern Painted Turtles (*Chrysemys picta picta*) in Massachusetts. On 23 September 2014, while undertaking surveys for Northern Red-bellied Cooter (*Pseudemys rubriventris*), we observed an adult Painted Turtle with an Eastern Elliptio attached to its hind left foot. The turtle was basking on a log in a large pond in Plymouth County (Figure 1d). On 24 April 2008, we observed a fingernail clam (*Sphaerium* sp.) attached to the front left foot of a young Eastern Painted Turtle (Figure 1e) in a small stream in Berkshire County.

We also observed one instance of an Eastern Elliptio attached to the right hind foot of a Common Snapping Turtle (*Chelydra serpentina*) in Hampshire County, Massachusetts, during a freshwater mussel survey on 11 July 2016 (Figure 1f). The turtle was moving across the bottom of the brook at the time we captured it.

It is possible that mussels become attached to turtles that forage in mussel aggregations. On 11 June 2011, we observed an adult female Wood Turtle (#44) feeding on the broken remains of a dead mussel along a river bank in Somerset County, Maine.

This is not the first report of passive transport of mussels by freshwater turtles: Kew (1893) reported an Eastern Elliptio attached to the jaw of a Snapping Turtle in Wisconsin. Further, Eastern Elliptio was reported by Darwin (1882) attached to the middle toe of a duck from Danversport, Massachusetts, spurring Darwin's hypotheses on assisted colonization by aquatic fauna. Darwin (1882) and others (Engel *et al.* 2008; Wood *et al.* 2008; Kappes and Haase 2012) have reported occurrences of other freshwater bivalves (e.g., Sphaeriidae) transported over land on the toes of pond-breeding salamanders, aiding in the dispersal of the molluscs to nearby ponds. Eastern Elliptio can be a protandrous hermaphrodite capable of self-fertilization, which is likely to aid in colonization of new areas by a small founding population (Downing *et al.* 1989). However, unlike the Sphaeriidae, Eastern Elliptio still requires a fish host for glochidial transformation. Thus, it is feasible that short overland dispersal of adult mussels by turtles could aid in the colonization of new habitats if fish hosts are present in the new area.

Closure (adduction) of the bivalve shell is controlled by the anterior and posterior adductor muscles, used in locomotion as well as a protective response to light or physical stimuli (Waller *et al.* 1999). A turtle foot or claw that touches the mantle of a gaped mussel will elicit adduction and attachment. This same response is employed by a crowsfoot brail dredge, used to collect freshwater mussels for research and commercial harvest (Miller and Payne 1993; Williams *et al.* 1993; Sietman *et al.* 2011). Collection of mussels using a brail dredge is associated with 50% or higher mortality (Williams *et al.* 1993; Waller *et al.* 1999), but it is unclear whether mussels attached to turtles would exhibit similar rates of mortality. The high mortality rate on a brail dredge may be caused by shell and soft tissue damage from the dredging itself and also from the active removal of mussels from the brails. A thick-shelled mussel attached to a turtle foot would likely undergo far lower forces than those on a brail dredge and are likely to be detached via their own release. Nevertheless, there is potential for soft tissue injury (i.e., to the foot, viscera, or mantle) that could result in mortality.

Species-specific differences exist in tolerance to emersion (i.e., being out of water), and shell closure is used to protect freshwater mussels from dessication during emersion (Waller *et al.* 1999; Gough *et al.* 2012). Eastern Elliptio is known to survive emersion for two or more days (P.D.H. pers. obs. during mussel salvage attempts following a dam removal in Pepperell, Massachusetts, 2015; S.L.J. pers. obs.

FIGURE 1. a. Adult Eastern Elliptio (*Elliptio complanata*) firmly attached to the foot of an adult male Wood Turtle (*Glyptemys insculpta*; #126) in Somerset County, Maine, USA, on 13 September 2013. Photo: M.T. Jones. b. Adult Eastern Elliptio firmly attached to the front foot of the same Wood Turtle (#126) in Somerset County, on 13 October 2013. Photo: M.T. Jones. c. Adult Eastern Elliptio firmly attached to the food of an adult female Wood Turtle (#452) in Somerset County, on 19 September 2015. Photo: M.T. Jones. d. Adult Eastern Elliptio firmly attached to the foot of an adult Eastern Painted Turtle (*Chrysemys picta*) in Plymouth County, Massachusetts, USA, on 23 September 2014. Photo: M.T. Jones. e. Fingernail clam (*Sphaerium* sp.) attached to the front foot of a young Eastern Painted Turtle in Berkshire County, Massachusetts, USA, on 24 April 2018. Photo: M.T. Jones. f. Adult Eastern Elliptio firmly attached to the food of an adult Snapping Turtle (*Chelydra serpentina*) in Hampshire County, Massachusetts, USA, on 11 July 2016. Photo: S.L. Johnson.

during several canal drawdown surveys in Holyoke, Massachusetts). Given this emersion tolerance, Eastern Elliptio is likely to survive short-term emersion during turtle-facilitated transport if they release near shore or when a turtle goes back into the water.

We suggest that Eastern Elliptio may be more susceptible than other more fragile-shelled mussel species (i.e., *Pyganodon* sp., *Anodonta* sp.) to turtle facilitated transport because of its relative abundance in New England, shell strength, and the strength of its closure. The relative contribution of this activity to Eastern Elliptio dispersal and/or mortality is currently unclear, but presumed to be relatively low. Although we did not specifically track the number of

times freshwater turtles were observed without mussels attached to their feet, the phenomenon appears to be a regular occurrence, as we observed it in three distinct watersheds and in three freshwater turtle species.

Author Contributions

Supervision: M.T.J.; Writing – Original Draft Preparation: M.T.J., L.L.W., and P.D.H.; Writing – Review & Editing: M.T.J., L.L.W., P.D.H., D.T.Y., and S.L.J.; Conceptualization: M.T.J. and L.L.W.; Investigation: M.T.J., L.L.W., D.T.Y., and S.L.J.; Funding Acquisition: M.T.J. and L.L.W.; Validation: S.L.J. and P.D.H.; Resources: M.T.J., L.L.W., and P.D.H.

Acknowledgements

This research was conducted under scientific collection permit 138-08SCRA from the Massachusetts Division of Fisheries and Wildlife. Our research protocols were approved by the University of Massachusetts Institutional Animal Care and Use Committee (protocols 24-02-01 and 27-02-02). Funding for this project was provided by the Massachusetts Division of Fisheries and Wildlife's Natural Heritage and Endangered Species Program, Maine Department of Inland Fisheries and Wildlife, and the Northeast Association of Fish and Wildlife Agencies' Regional Conservation Needs award. We gratefully acknowledge the field support of Sean Werle.

Literature Cited

Amyot, J.P., and J.A. Downing. 1997. Seasonal variation in vertical and horizontal movement of the freshwater bivalve *Elliptio complanata* (Mollusca: Unionidae). Freshwater Biology 37: 345–354. https://doi.org/10.1046/j.1365-2427.1997.00158.x

Balfour, D.L., and L.A. Smock. 1995. Distribution, age structure, and movements of the freshwater mussel *Elliptio complanata* (Mollusca: Unionidae) in a headwater stream. Journal of Freshwater Ecology 10: 255–268. https://doi.org/10.1080/02705060.1995.9663445

Darwin, C. 1882. On the dispersal of freshwater bivalves. Nature 25: 529–530. https://doi.org/10.1038/025529f0

Downing, J.A., J.P. Amyot, M. Pérusse, and Y. Rochon. 1989. Visceral sex, hermaphroditism, and protandry in a population of the freshwater bivalve *Elliptio complanata*. Journal of the North American Benthological Society 8: 92–99. https://doi.org/10.2307/1467405

Engel, E., K. Groh, R. Griffiths, L. Wood, and L. Schley. 2008. Interactions between freshwater mussels and newts: a novel form of parasitism? Amphibia-Reptilia 29: 457–462. https://doi.org/10.1163/156853808786230433

Gough, H.M., A.M. Gascho Landis, and J.A. Stoeckel. 2012. Behaviour and physiology are linked in the responses of freshwater mussels to drought. Freshwater Biology 57: 2356–2366. https://doi.org/10.1111/fwb.12015

Jones, M.T. 2009. Spatial ecology, population structure, and conservation of the Wood Turtle, *Glyptemys insculpta*, in central New England. Ph.D. thesis, University of Massachusetts, Amherst, Massachusetts, USA. https://doi.org/10.7275/hn42-4v25

Jones, M.T., H.P. Roberts, and L.L. Willey. 2018. Conservation plan for the Wood Turtle (*Glyptemys insculpta*) in the northeastern United States. Massachusetts Division of Fisheries and Wildlife, Westborough, Massachusetts, USA.

Kappes, H., and P. Haase. 2012. Slow, but steady: dispersal of freshwater molluscs. Aquatic Sciences 74: 1–14. https://doi.org/10.1007/s00027-011-0187-6

Kew, H.W. 1893. The Dispersal of Shells: an Inquiry into the Means of Dispersal Possessed by Fresh-water and Land Mollusca. Kegan Paul, Trench, Trübner, London, United Kingdom. https://doi.org/10.5962/bhl.title.152720

Lellis, W.A., B. St. John White, J.C. Cole, C.S. Johnson, J.L. Devers, E. van Snik Gray, and H.S. Galbraith. 2013. Newly documented host fishes for the eastern elliptio mussel *Elliptio complanata*. Journal of Fish and Wildlife Management 4: 75–85. https://doi.org/10.3996/102012-jfwm-094

Miller, A.C., and B.S. Payne. 1993. Qualitative versus quantitative sampling to evaluate population and community characteristics at a large-river mussel bed. American Midland Naturalist 130: 133–145. https://doi.org/10.2307/2426282

Newton, T.J., S.J. Zigler, and B.R. Gray. 2015. Mortality, movement and behaviour of native mussels during a planned water-level drawdown in the Upper Mississippi River. Freshwater Biology 60: 1–15. https://doi.org/10.1111/fwb.12461

Schwalb, A.N., and M.T. Pusch. 2007. Horizontal and vertical movements of unionid mussels in a lowland river. Journal of the North American Benthological Society 26: 261–272. https://doi.org/10.1899/0887-3593(2007)26[261:havmou]2.0.co;2

Sietman, B.E., S.D. Whitney, D.E. Kelner, K.D. Blodgett, and H.L. Dunn. 2011. Post-extirpation recovery of the freshwater mussel (Bivalvia: Unionidae) fauna in the upper Illinois River. Journal of Freshwater Ecology 16: 273–281. https://doi.org/10.1080/02705060.2001.9663813

Terui, A., and Y. Miyazaki. 2015. A "parasite-tag" approach reveals long-distance dispersal of the riverine mussel *Margaritifera laevis* by its host fish. Hydrobiologia 760: 189–196. https://doi.org/10.1007/s10750-015-2325-y

Waller, D.L., S. Gutreuter, and J.J. Rach. 1999. Behavioral responses to disturbance in freshwater mussels with implications for conservation and management. Journal of the North American Benthological Society 18: 381–390. https://doi.org/10.2307/1468451

Williams, J.D., M.L. Warren, Jr., K.S. Cummings, J.L. Harris, and R.J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18: 6–22. http://doi.org/d7t3vm

Received 15 October 2019
Accepted 1 April 2020

The Canadian Field-Naturalist

Note

First record of an Italian Wall Lizard (*Podarcis siculus*) in British Columbia, Canada

Gavin F. Hanke[1,*] **and Guntram Deichsel**[2]

[1]Royal British Columbia Museum, 675 Belleville Street, Victoria, British Columbia V8W 9W2 Canada
[2]Friedrich-Ebert-Str 62, Biberach an der Riss, Germany DE-88400
*Corresponding author: ghanke@royalbcmuseum.bc.ca

Hanke, G.F., and G. Deichsel. 2020. First record of an Italian Wall Lizard (*Podarcis siculus*) in British Columbia, Canada. Canadian Field-Naturalist 134(1): 60–63. https://doi.org/10.22621/cfn.v134i1.2483

Abstract
Italian Wall Lizard (*Podarcis siculus*) is known from scattered locations in the United States, including Orcas Island, Washington, where a population went unreported for about a decade, but was confirmed in 2017. On 19 June 2019, a single adult female *P. siculus* was caught in an industrial area along the northern arm of the Fraser River in Vancouver, British Columbia; this represents the first record of this species on the loose in Canada. No other *P. siculus* were sighted in the Vancouver area. We assume this Canadian *P. siculus* was a lone stow-away and had not deposited eggs. We could not determine how it entered the province.

Key words: British Columbia; first record; Italian Wall Lizard; introduced species; *Podarcis siculus*

Humans have purposely or accidentally introduced non-native reptiles and amphibians in many parts of the world (Lever 2003). European lacertids, including Western Green Lizard (*Lacerta bilineata*), Ocellated Lizard (*Timon lepidus*), Ibiza Wall Lizard (*Podarcis pityusensis*), Italian Wall Lizard (*Podarcis siculus*), and Common Wall Lizard (*Podarcis muralis*), have appeared in North America with all but *P. pityusensis* and *T. lepidus* establishing populations (Lever 2003; Burke and Deichsel 2008; Kraus 2009). Two *Podarcis* species occur along the Pacific coast of North America, with Common Wall Lizard arriving first, in 1967, and spreading rapidly in southwestern British Columbia (Deichsel and Schweiger 2004; Matsuda *et al.* 2006; Engelstoft *et al.* 2020). In 1994, Italian Wall Lizards were released in southern California, and the species is now known from several locations (Deichsel *et al.* 2010; Hollingsworth and Thomson 2016). This species is also established on Orcas Island, Washington (L. Hallock pers. comm. 15 October 2018). As of 2019, the Orcas Island *P. siculus*, which were mistakenly identified as *P. muralis*, had existed there for 12 years (C. Raimond unpubl. report, sent to A. Leaché). Here, we document the first occurrence of *P. siculus* in British Columbia.

A single female *P. siculus* (Figure 1; RBCM 2187) was caught by Cathy Judd on 19 June 2019, at Unit 8, 8385 St. George Street (49.208641°N, 123.094219°W), Vancouver, British Columbia (Figure 2). The location is bound by railroad tracks, the northern arm of the Fraser River delta, and residential areas, each representing a potential dispersal route for invading *Podarcis*. The lizard's presence was reported to A. Veldhoen, and a photograph was forwarded to the Royal British Columbia Museum for identification. On 25 June 2019, the lizard was hand carried to the Royal British Columbia Museum, anaesthetized using Oragel (20% benzocaine, Church & Dwight Canada Corp., Mississauga, Ontario, Canada), then frozen overnight once it was unresponsive. The lizard was thawed, a liver sample was taken and preserved in 95% ethanol for future genetic work, and the rest of the lizard was fixed in 10% formaldehyde. After a week, the lizard was transferred to 70% ethanol for permanent storage. Latitude and longitudinal coordinates for the collection locality were generated using Google Earth.

In the United States of America, *P. siculus* is known from Kansas, Missouri, New Jersey, Long Island, New York, Connecticut, Massachusetts, Penn-

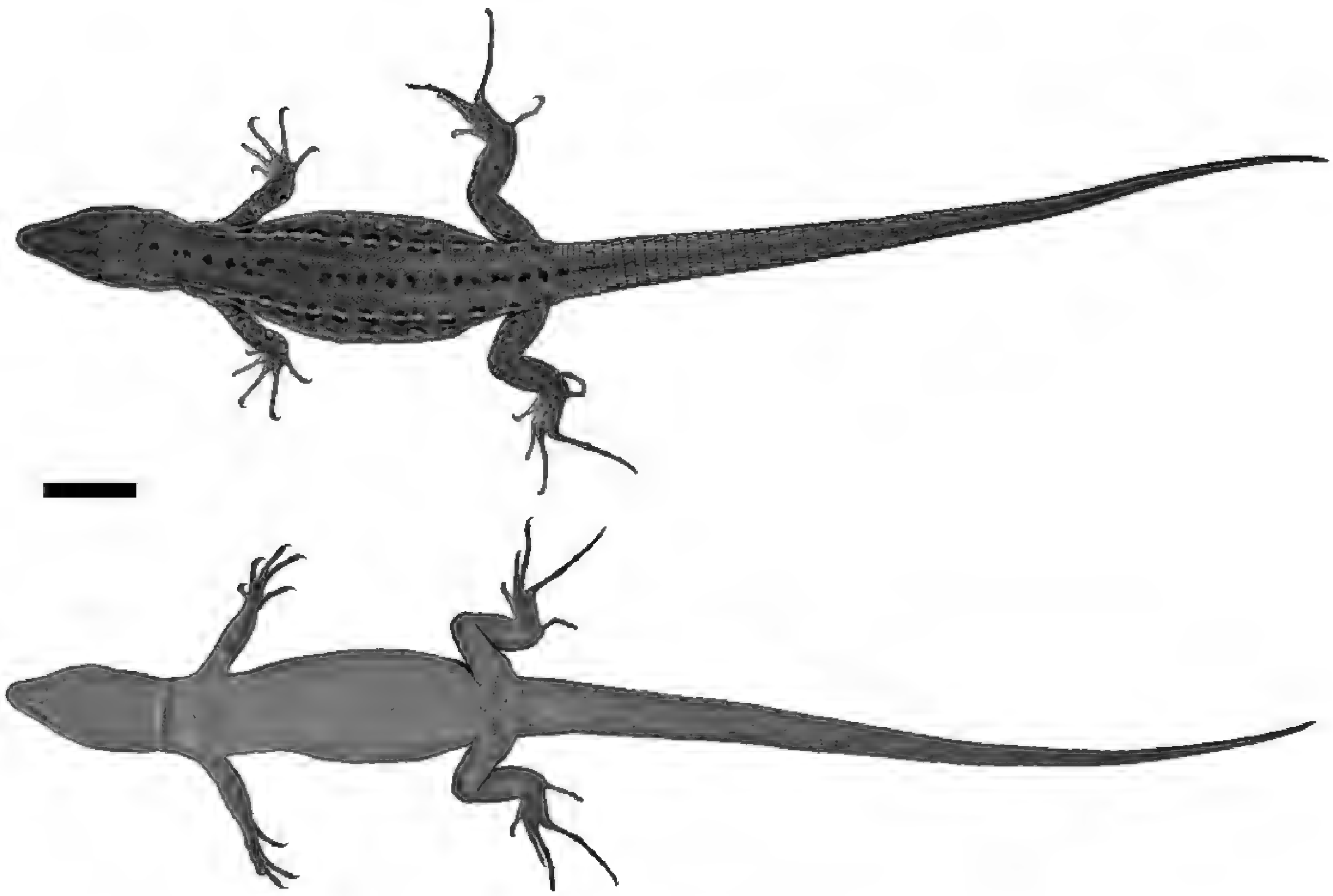


FIGURE 1. Dorsal and ventral views of a female Italian Wall Lizard (*Podarcis siculus*; RBCM 2187) found in Vancouver, British Columbia, Canada. Total length = 143 mm, snout to vent length = 59 mm, scale bar = 1 cm. Photo: G. Hanke.

sylvania, Virginia, California (Lever 2003; Kraus 2009; Burke 2010; Deichsel *et al.* 2010; Briggler *et al.* 2015; Donihue *et al.* 2015; Hollingsworth and Thomson 2016), and Washington (Orcas Island). According to A. Leaché (pers. comm. 16 October 2018), C. Raimond was the first to report wall lizards at Bullock's Permaculture Homestead, 0.7 km northwest of Deer Harbor Marina (48.626991°N, 123.011423°W), Orcas Island, Washington on 13 May 2017, with accompanying photographs uploaded to Flickr on 14 May 2017. Raimond suggested that the lizards he photographed were *P. muralis* from Vancouver Island; however, we have reidentified the photographed lizards as *Podarcis siculus campestris*. At least eight individuals of different age classes were seen on Orcas Island along a partly shaded, rocky, south-facing slope. According to Raimond's 2017 report, landowners knew that these lizards had been on the property for at least 10 years. In Figure 2, the dot on Orcas Island, centred on Raimond's original sighting, represents the potential range of *P. siculus* after a decade of unassisted dispersal, assuming range expansion rate is the same as estimated by Burke (2005) and Burke and Deichsel (2008).

To our knowledge, RBCM 2187 represents the first record of *P. siculus* on the loose in Canada. The Canadian specimen was collected at the office of Honeycomb Direct Mail Inc., beside Rent-a-Tent Canada in Vancouver, about 65 km north of the *P. siculus* population on Orcas Island, Washington (Figure 2). As no hatchlings have been seen where RBCM 2187 was collected, we assume it was a lone stowaway and had not deposited eggs. It is possible that this Canadian specimen stowed away in camping gear used on Orcas Island, or arrived in a mail shipment from Europe or elsewhere in North America. The Orcas Island specimens photographed by C. Raimond and RBCM 2187 have colouration consistent with *P. s. campestris*, the northern subspecies ranging from easternmost France and the southern tip of Switzerland, throughout the northern two-thirds of Italy, east to the coasts and coastal islands of Slovenia, Croatia, Bosnia/Herzegovina, and all but the southern tip of Corsica (Speybroeck *et al.* 2016).

The rapid spread of *P. muralis* in British Columbia, including the Osoyoos specimen, which travelled from Vancouver Island to Osoyoos in a shipment of grapes (Engelstoft *et al.* 2020), and the recent appearance of *P. siculus* in Vancouver indicate that the potential for accidental transport of *Podarcis* is high. Because *P. siculus* is established on Orcas Island in the same climatic zone as southern Vancouver Island

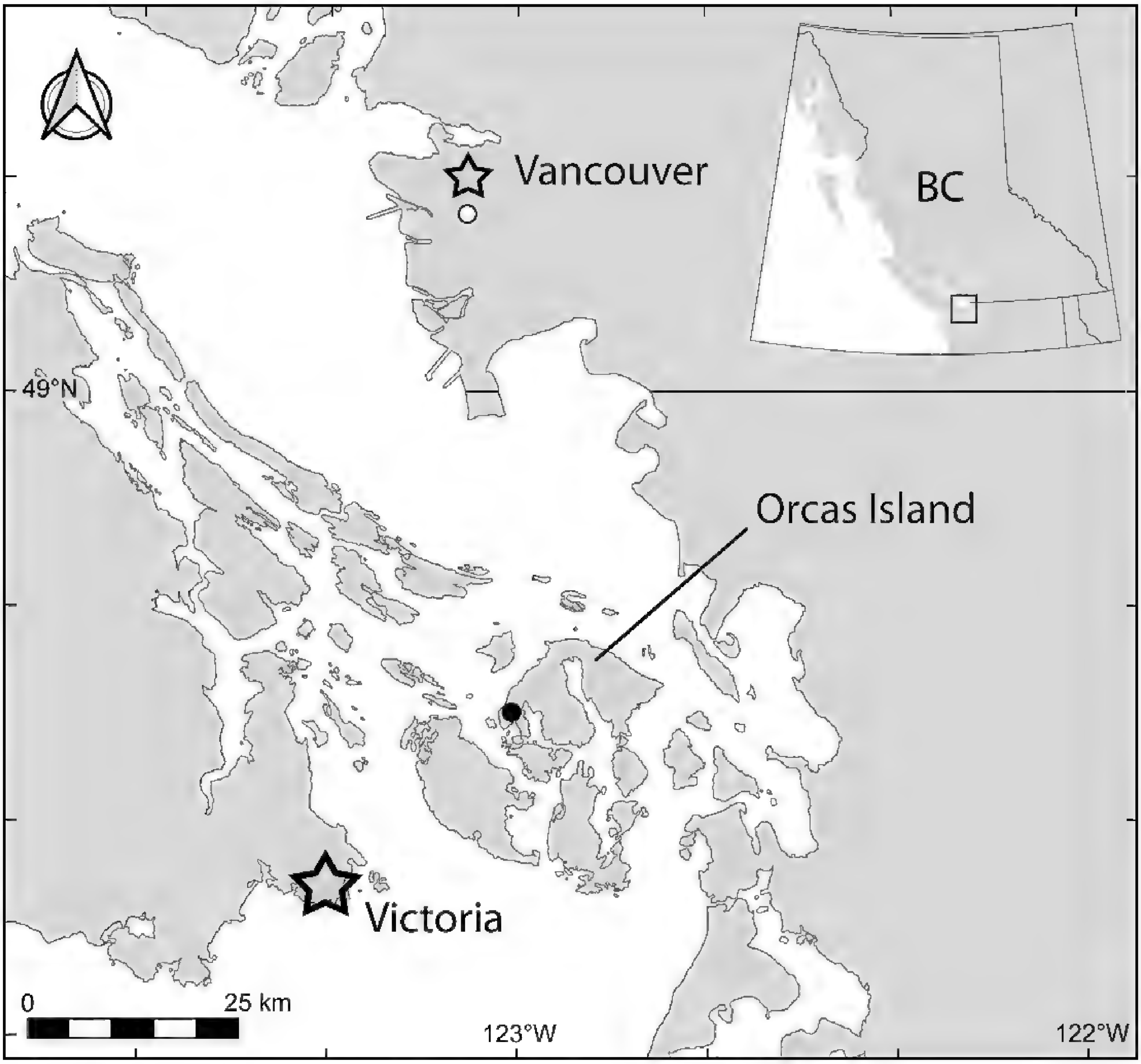


FIGURE 2. Locations of Italian Wall Lizards (*Podarcis siculus*) captured in Vancouver, British Columbia (white dot), and sighted on Orcas Island, Washington (black dot). Note that the dot on Orcas Island has a radius of ~1 km representing the potential unassisted range expansion after one decade.

and Vancouver, is successful in cooler climates elsewhere in North America (Burke *et al.* 2002) and is known to eat other lizards and lizard eggs and attempt to ingest animals as large as shrews (Capula and Aloise 2011; Grano *et al.* 2011), it represents a high-risk invader in southwestern British Columbia. Given that *P. muralis* is already established as an invasive species in British Columbia, the addition of a second Podarcis species would intensify the impact on the native fauna of southwestern British Columbia.

Author Contributions

Writing – Original Draft: G.F.H. and G.D.; Writing –Review & Editing: G.F.H. and G.D.; Species identification: G.F.H. and G.D.

Acknowledgments

We thank Cathy Judd for capturing the single specimen and for delivering it to the Royal British Columbia Museum. Thanks also to Ashlea Veldhoen (Habitat Acquisition Trust) for forwarding the inquiry regarding this mainland occurrence. We thank Lisa Hallock (Washington Department of Fish and Wildlife) and Adam Leaché (Department of Biology, University of Washington) for information on *Podarcis siculus* from Orcas Island.

Literature Cited

Briggler, J.T., R.L. Rimer, and G. Deichsel. 2015. First record of the Northern Italian Wall Lizard (*Podarcis siculus campestris*) in Missouri. IRCF Reptiles &

Amphibians: Conservation and Natural History 22: 43–45.

Burke, R.L. 2005. "Italian immigrants" flourish on Long Island. Hofstra Horizons Fall: 14–18.

Burke, R.L. 2010. *Podarcis siculus campestris* (Italian Wall Lizard). Herpetological Review 41: 514.

Burke, R.L., and G. Deichsel. 2008. Lacertid lizards introduced into North America: history and future. Pages 347–353 *in* Urban Herpetology. *Edited by* J.C. Mitchell, R.E. Jung Brown, and B. Bartholomew. Society for the Study of Amphibians and Reptiles, Salt Lake City, Utah, USA.

Burke, R.L., A.A. Hussain, J.M. Storey, and K.B. Storey. 2002. Freeze tolerance and supercooling ability in the Italian Wall Lizard, *Podarcis sicula*, introduced to Long Island, New York. Copeia 2002: 836–842. https://doi.org/10.1643/0045-8511(2002)002[0836:ftasai]2.0.co;2

Capula, M., and G. Aloise. 2011. Extreme feeding behaviours in the Italian Wall Lizard, *Podarcis siculus*. Acta Herpetologica 6: 11–14.

Deichsel, G., G. Nafis, and J. Hakim. 2010. *Podarcis siculus* (Italian Wall Lizard). Herpetological Review 41: 513–514.

Deichsel, G., and S. Schweiger. 2004. *Podarcis muralis* (Common Wall Lizard). Herpetological Review 35: 289–290.

Donihue, C.M., M.R. Lambert, and G.J. Watkins-Colwell. 2015. *Podarcis sicula* (Italian Wall Lizard) habitat, invasion of suburban area of New England. Herpetological Review 46: 260–261.

Engelstoft, C., J. Robinson, D. Fraser, and G. Hanke. 2020. Recent rapid expansion of Common Wall Lizards (*Podarcis muralis*) in British Columbia, Canada. Northwestern Naturalist 101: 50–55. https://doi.org/10.1898/1051-1733-101.1.50

Grano, M., C. Cattaneo, and A. Cattaneo. 2011. A case of cannibalism in *Podarcis siculus campestris* De Betta, 1857 (Reptilia, Lacertidae). Biodiversity Journal 2: 151–152.

Hollingsworth, B., and A. Thomson. 2016. *Podarcis siculus* (Italian Wall Lizard). Herpetological Review 47: 424.

Kraus, F. 2009. Alien Reptiles and Amphibians: a Scientific Compendium and Analysis. Invading nature: Springer series in invasion ecology 4. Springer, New York, New York, USA.

Lever, C. 2003. Naturalized Reptiles and Amphibians of the World. Oxford University Press, Oxford, United Kingdom.

Matsuda, B.M., D.M. Green, and P.T. Gregory. 2006. Amphibians and Reptiles of British Columbia. Royal BC Museum, Victoria, British Columbia, Canada.

Speybroeck, J., W. Beukema, B. Bok, J. Van Der Voort, and I. Velikov. 2016. Field Guide to the Amphibians and Reptiles of Britain and Europe. Bloomsbury, London, United Kingdom.

Received 2 March 2020
Accepted 13 April 2020

The Canadian Field-Naturalist

Diet of a rare Canadian fish species, Carmine Shiner (*Notropis percobromus*) in the Birch River, Manitoba, Canada

Eva C. Enders[1,*], Tharshinidevy Nagalingam[1], Amanda L. Caskenette[1], Tyana A. Rudolfsen[1], Colin Charles[1], and Douglas A. Watkinson[1]

[1]Freshwater Institute, Fisheries and Oceans Canada, Winnipeg, Manitoba R3T 2N6 Canada
[*]Corresponding author: Eva.Enders@dfo-mpo.gc.ca

Enders, E.C., T. Nagalingam, A.L. Caskenette, T.A. Rudolfsen, C. Charles, and D.A. Watkinson. 2020. Diet of a rare Canadian fish species, Carmine Shiner (*Notropis percobromus*) in the Birch River, Manitoba, Canada. Canadian Field-Naturalist 134(1): 64–70. https://doi.org/10.22621/cfn.v134i1.2301

Abstract

Due to its restricted occurrence and existing threats, Carmine Shiner (*Notropis percobromus*) has been listed as threatened under the Canadian *Species at Risk Act*. Little is known about Carmine Shiner biology, and understanding its diet composition will help inform future conservation actions. Consequently, the aim of this study was to analyze the diet of Carmine Shiner. Fish were caught throughout the open water season using beach seines, and stomach contents were analyzed. Carmine Shiner feed on a variety of terrestrial and aquatic insects. Diets did not differ substantially between year classes, and we observed no clear temporal trends in diet composition.

Key words: Species at risk; Carmine Shiner; diet; stomach contents

Introduction

In Canada, Carmine Shiner (*Notropis percobromus* (Cope, 1871)) is currently listed as Threatened under the *Species at Risk Act* (SARA Registry 2019). The reason for this designation is that, in Canada, the species occurs only in a restricted area in southeastern Manitoba including the Birch River where threats such as pollution and habitat loss exist (COSEWIC 2018). The major threat to the species is ongoing alterations in water flow as a result of stream regulation (Fisheries and Oceans Canada 2013). The life history, habitat requirements, biology, and physiology of the species are not well understood, but research is improving our understanding of temperature preference, habitat use, and metabolic rate (Stol *et al.* 2013; Carr *et al.* 2015; Macnaughton *et al.* 2019).

Analyzing the diet of Carmine Shiner increases our understanding of its food requirements and helps us evaluate threats to the species. This information may inform conservation measures leading to an improved recovery strategy and preservation of the population in Canada (Fisheries and Oceans Canada 2013). Currently, the available information on the biology of Carmine Shiner, specifically, diet, is insufficient to identify factors that might limit its recovery. Such research is an urgent priority (Fisheries and Oceans Canada 2015; COSEWIC 2018).

At the southern part of its distribution in the Ozarks (in Missouri, Arkansas, Oklahoma, and Kansas, USA), Carmine Shiner has been described as a consumer of aquatic and terrestrial insects (Hoover 1989). Aquatic caddisfly larvae constitute the bulk of the diet, but terrestrial insects, fish eggs, algae, diatoms, and inorganic material are also consumed (Hoover 1989). Juvenile Carmine Shiner prefer algae and diatoms to insects. In addition, food competition among minnow species results in greater dietary specialization by Carmine Shiner on midges (Chironomidae; Hoover 1989). In the Birch River, Carmine Shiners have been observed darting to the water surface to feed (E.C.E. pers. obs.) suggesting that terrestrial insects may be an important food source.

In this study, we evaluated the food consumption of Carmine Shiner in the Birch River, a tributary of the Winnipeg River in Manitoba, Canada. Our objectives were to: (1) study the diet composition of Carmine Shiner; (2) compare the diet composition between year classes; and (3) analyze temporal (June to October) variations in diet composition.

Methods

The Birch River is situated in the Winnipeg River watershed in southeastern Manitoba (Figure 1). Originating in Birch Lake, it flows ~17 km north to

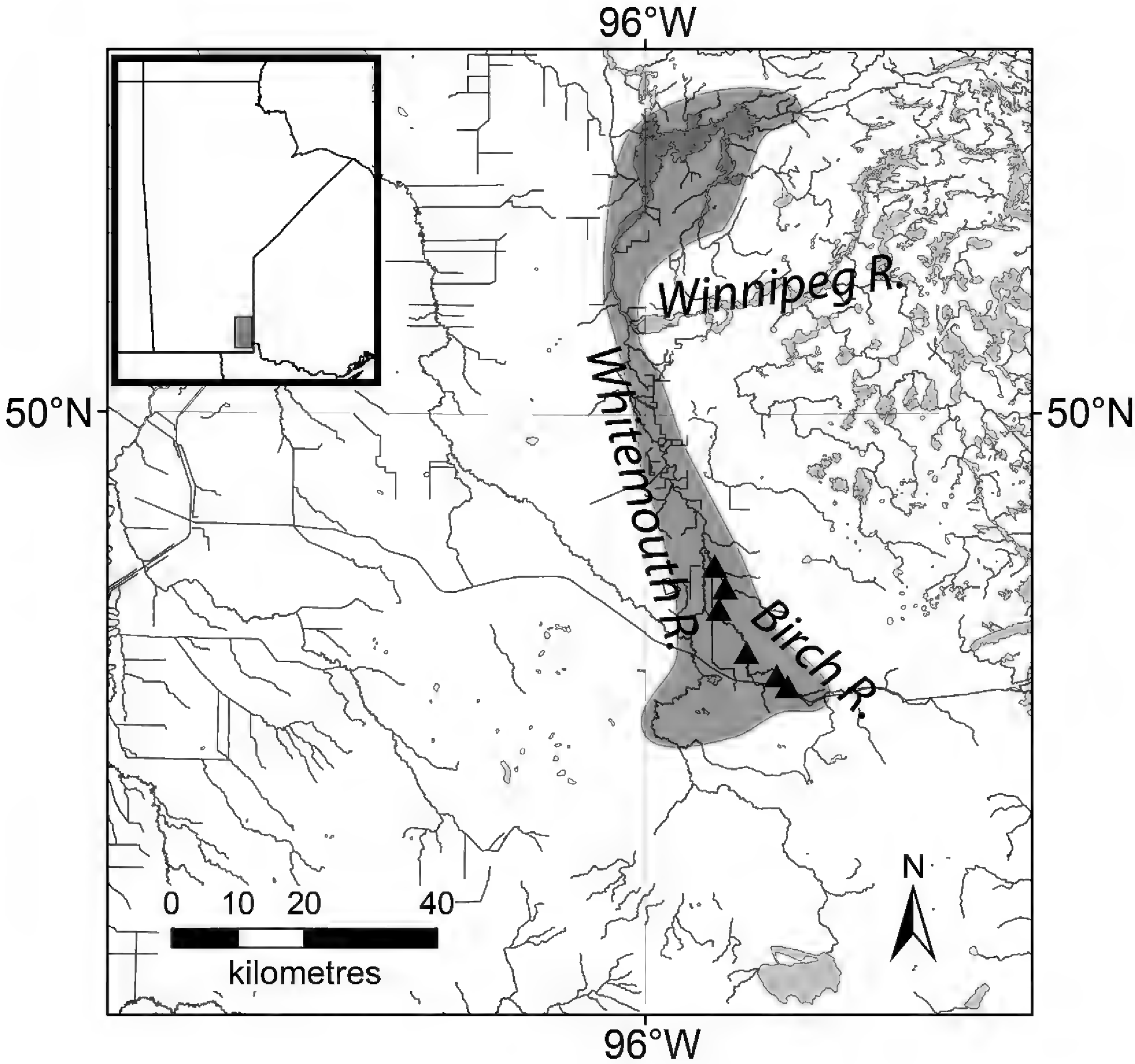


FIGURE 1. Location of the study area in the Birch River in the Winnipeg River watershed in Manitoba, Canada with the sampling sites shown by triangles. The range of Carmine Shiner (*Notropis percobromus*) in Manitoba is indicated in dark grey.

its confluence with the Boggy River, then continues for another ~52 km northwest to its confluence with the Whitemouth River. The river is unregulated and the upper portions of its watershed have low levels of anthropogenic disturbance (Clarke 1998). The Birch River is a meandering, low-gradient watercourse. Water depth is generally less than 1 m during the summer, fall, and winter. Silt, sand, and gravel are the dominant substrate types. The watershed has a drainage area of 864 km^2 (Carr *et al.* 2015).

Carmine Shiner is a slender, elongate minnow found mainly in clear, brown-coloured, fast-flowing creeks and small rivers (Watkinson and Sawatzky 2013). It can be sexually mature at the age of one year and has a lifespan of at least three years (COSEWIC 2018). In Manitoba, its maximum observed fork length is 67 mm. It is olive green to silvery white in colour, but spawning adults develop bright red cheeks and fin bases. Spawning Carmine Shiners have been captured over clean gravel or cobble substrates and are known to spawn in early summer (Stewart and Watkinson 2007). Predators are not well known, but, in Manitoba, they probably include a number of piscivorous fish and bird species (Watkinson and Sawatzky 2013).

In Canada, Carmine Shiner is found only in Manitoba; it has been captured in the Winnipeg, Bird, Whitemouth, and Birch Rivers and in the Pinawa Channel (Watkinson and Sawatzky 2013). The population is not connected to southern populations found in the United States. Carmine Shiner is not the target of any known fishery and has no direct economic im-

portance, but it is considered to be of "significant biological and scientific interest" (Fisheries and Oceans Canada 2013: iii). The species is sensitive to anthropogenic disturbances because of its limited distribution and abundance. The Manitoba population is at the northern limit of the species' current range and may possess unique characteristics related to local adaptation (Stewart and Watkinson 2007).

Sampling was conducted approximately every two weeks from June to October 2011 in the Birch River. At each sample location, fish were collected with three passes of a 9.14-m long by 1.82-m high seine with a 1.82 × 1.82-m bag and 4.76-mm mesh. To maintain an equal sampling area between locations, one end of the seine was held stationary on shore and the other end was stretched out along the shore in an upstream direction then pulled downstream in a half circle. Fish were removed from the seine after each haul and placed in a holding tub. Fish were preserved in 95% ethanol on site for later identification, measurement of fork length, and collection of stomach contents for analysis.

The stomach contents of 514 Carmine Shiners (mean fork length 34.9 mm, SD 12.7 mm) were analyzed. Individual fish preserved in ethanol were taken out of the sample bottle. The fork length was measured to the nearest mm. Subsequently, under a dissecting scope (model SMZ 1000; Nikon, Tokyo, Japan), the fish were dissected on a 60-mm-diameter wax-bottomed glass Petri dish and the esophagus, stomach, and intestines were extracted. Individual food items were then removed from the esophagus and front part of the stomach and put on an identification tray. Food particles were counted and identified to the lowest feasible taxonomic level using taxonomic keys and descriptions (Borror and White 1970; Merritt and Cummins 1996; Marshall 2013; Evans 2014). The identified food particles were then put in a pre-weighed aluminum boat (0.12 mL, model 12577-070; VWR International, Radnor, Pennsylvania, USA), dried for 24 h in a drying chamber at 70°C, and individually weighed (dry weight).

To analyze ontogenetic diet shifts, we divided the sampled fish into size classes (Figure 2). An independent mixture model was used to estimate size of the various age classes (Rennie *et al.* 2019). The mixture model was fitted using the mix() function in the depmixS4 package (Visser and Speekenbrink 2010) in R version 3.40 (R Core Team 2017). A Gaussian distribution was used to classify the groups, using either one or two hidden states (age classes) changing temporally as young-of-the-year (YOY) shiners did not occur in catches before late July (Figure 2).

For each size class, we then calculated the average proportion of each prey category in the stomach contents. To compare dietary overlap between size classes, we used the Schoener index (SI) based on prey abundance (Schoener 1970):

$$a = 1 - 0.5 \cdot \sum_{i=1}^{n} \left| P_{xi} - P_{yi} \right|$$

where a is the SI value, P_{xi} is the proportion of the ith prey item in age category or species class x, and P_{yi} is the proportion of the ith prey item in age category or

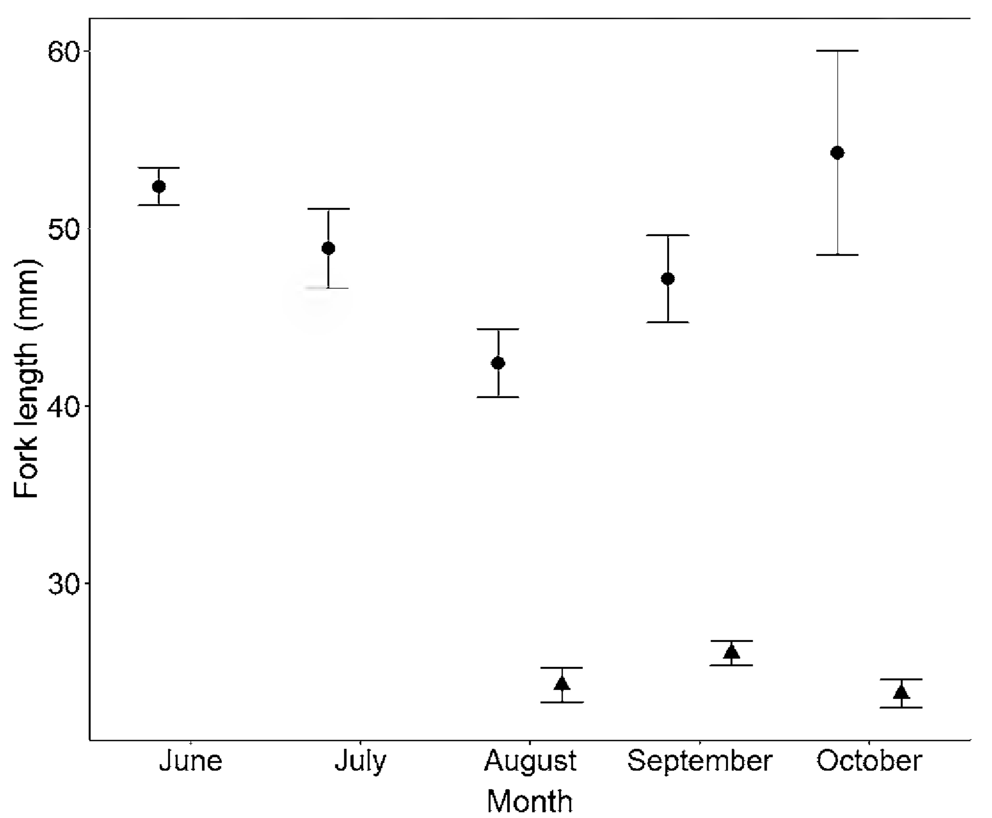


FIGURE 2. Categorization of young-of-the-year (●) and ≥1 year classes (▲) of Carmine Shiner (*Notropis percobromus*) in the Birch River, Manitoba, Canada, based on fork length (bars indicate 95% CI, $n = 514$).

class *y*. An SI value of 0 represents no overlap; an SI value of 1 indicates complete overlap, and SI values >0.6 proposes a certain degree of food competition between age classes. All database manipulation and data analyses were done in R version 3.4.0 (R Core Team 2017).

Results

We analyzed the stomach contents of 514 Carmine Shiners, 349 (67.1%) of which yielded at least one prey item; the other 165 (32.9%) stomachs were empty (Figure 3). Among fish with at least one consumed prey item, on average, 2.1 ± 0.2 (mean ± SD) invertebrates were found in their stomachs, but up to 36 prey items were found in a single fish. Carmine Shiners consumed a variety of terrestrial and aquatic invertebrates. The major groups found among the prey items included Coleoptera (59%), Hymenoptera (12%), Diptera (6%), and Hemiptera (6%). Hydraenidae made up 71% of the coleopteran insects with the major species being a *Hydraena* sp. The other families of coleopteran insects found were unidentified (10.8%), Hydrophilidae (7.6%), Staphylinidae (2.7%), Carabidae (1.6%), Dytiscidae (0.6%), Coccinellidae (0.2%), and unidentified weevils (0.6%). The other groups of insects, which were further identified to a lower taxonomic group included Arachnida, Hemiptera (aphids, mirids, and tingids), Hymenoptera (Braconidae, Chalcidoidea, Formicidae, and Ichneumonidae), Phthiraptera, and Thysanoptera. Most identified prey items are terrestrial; only Dytiscidae, Hydraenidae, and Hydrophilidae are aquatic.

The number of prey items consumed by Carmine Shiners varied among sampling months (Figure 4), with the largest numbers of invertebrates (4.0 ± 0.5 observed in August. We observed dietary overlap between YOY and older classes (≥1 year) of Carmine Shiners (SI 0.86). Although the frequency of occurrence of various prey categories varied among sampling months, no temporal trend was detected (Figure 5). In August and September, Carmine Shiner fed dominantly on Coleoptera. YOY Carmine Shiners consumed Arachnida, Coleoptera, Diptera, Hemiptera, and Hymenoptera in August, September, and October. Neuroptera, Psocoptera, Thysanoptera, Trichoptera, and Phthiraptera were not found in stomachs of YOY. Older year classes fed on Arachnida, Coleoptera, Diptera, and Hemiptera during June, July, and August. Thiraptera was observed in the diet only in June. All prey items other than Hemiptera were consumed in September. In October, only Coleopterans were observed in older year classes. Neuroptera, Psocoptera, Thysanoptera, and Trichoptera were not consumed by older year classes in any of the sampling months.

Discussion

Carmine Shiners are visual feeders that consume a variety of seasonal food items. Stomach content analysis indicated that they consumed a wide prey base, reflecting their dynamic habitat conditions, i.e., lentic versus lotic, spatial river gradient, and seasonal succession of prey availability. Stomach contents included Coleoptera (the most dominant prey category), Hymenoptera, Diptera, and Hemiptera. In particular, Hydraenidae were commonly observed in the diet. Hydraenidae are also referred to as minute moss beetles, as they are often found in moss or accumulations of moist or wet dead leaves, sticks, and twigs along the margins of streams and rivers (Merritt and Cummins 1996). The proximity of the Hydraenidae habitat to the river margins (Borer and White 1998;

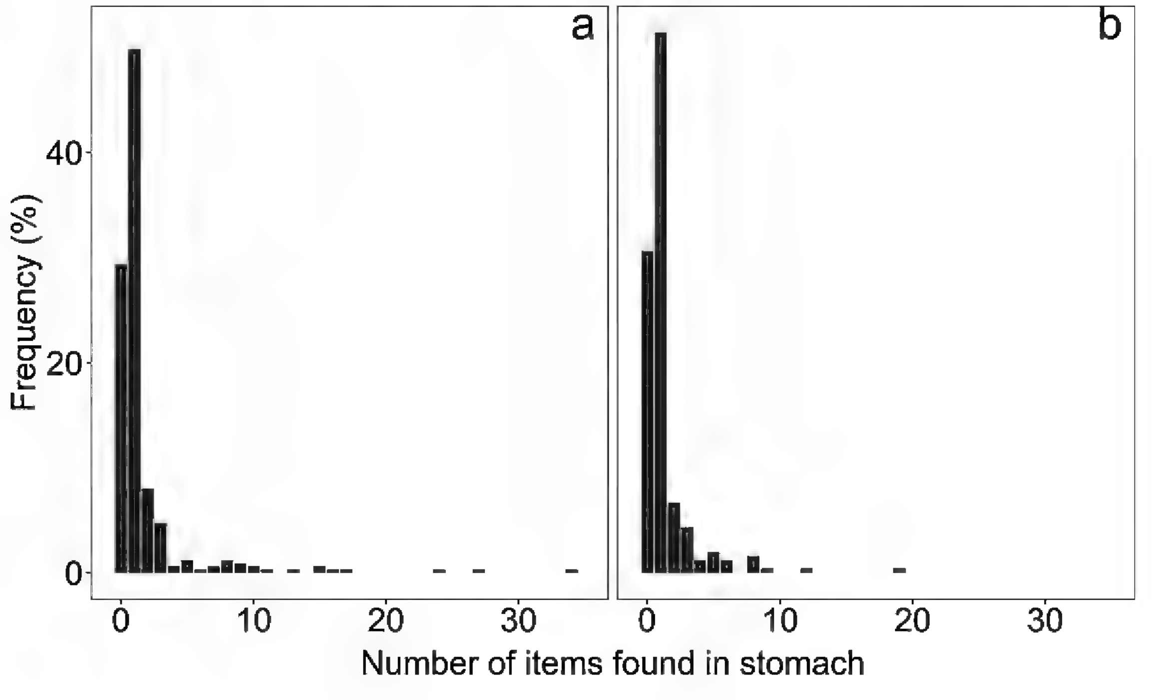


FIGURE 3. Frequency distribution of items found in the stomach contents of a. young-of-the-year and b. ≥1 year classes of Carmine Shiner (*Notropis percobromus*) in the Birch River, Manitoba, Canada (n = 514).

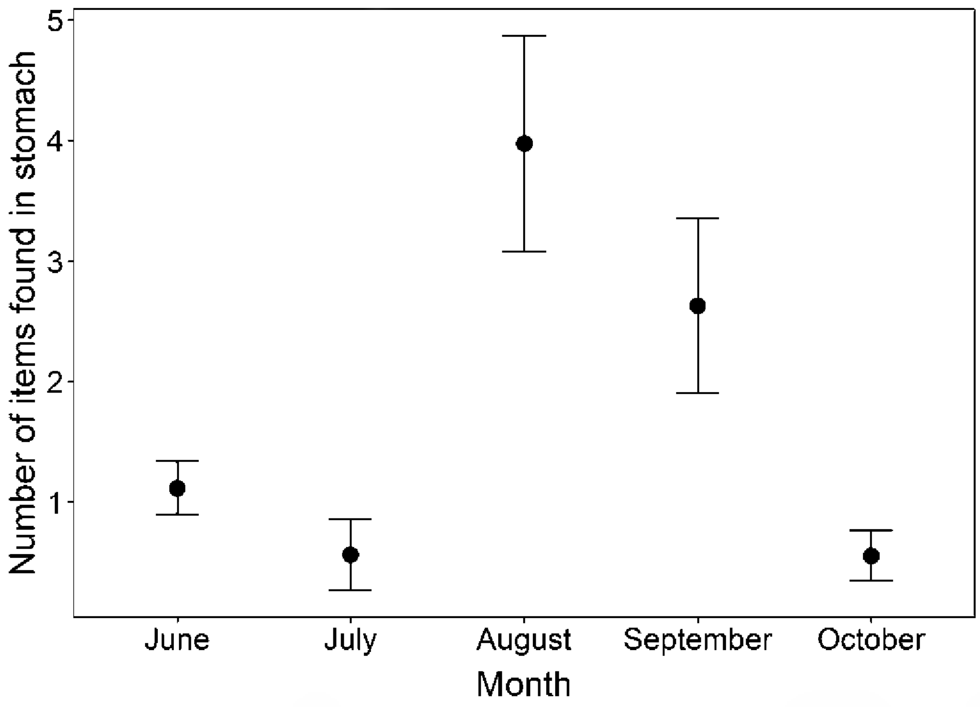


FIGURE 4. Mean number of prey items per stomach observed in Carmine Shiner (*Notropis percobromus*) in June to October in the Birch River, Manitoba, Canada (bars indicate 95% CI, $n = 514$).

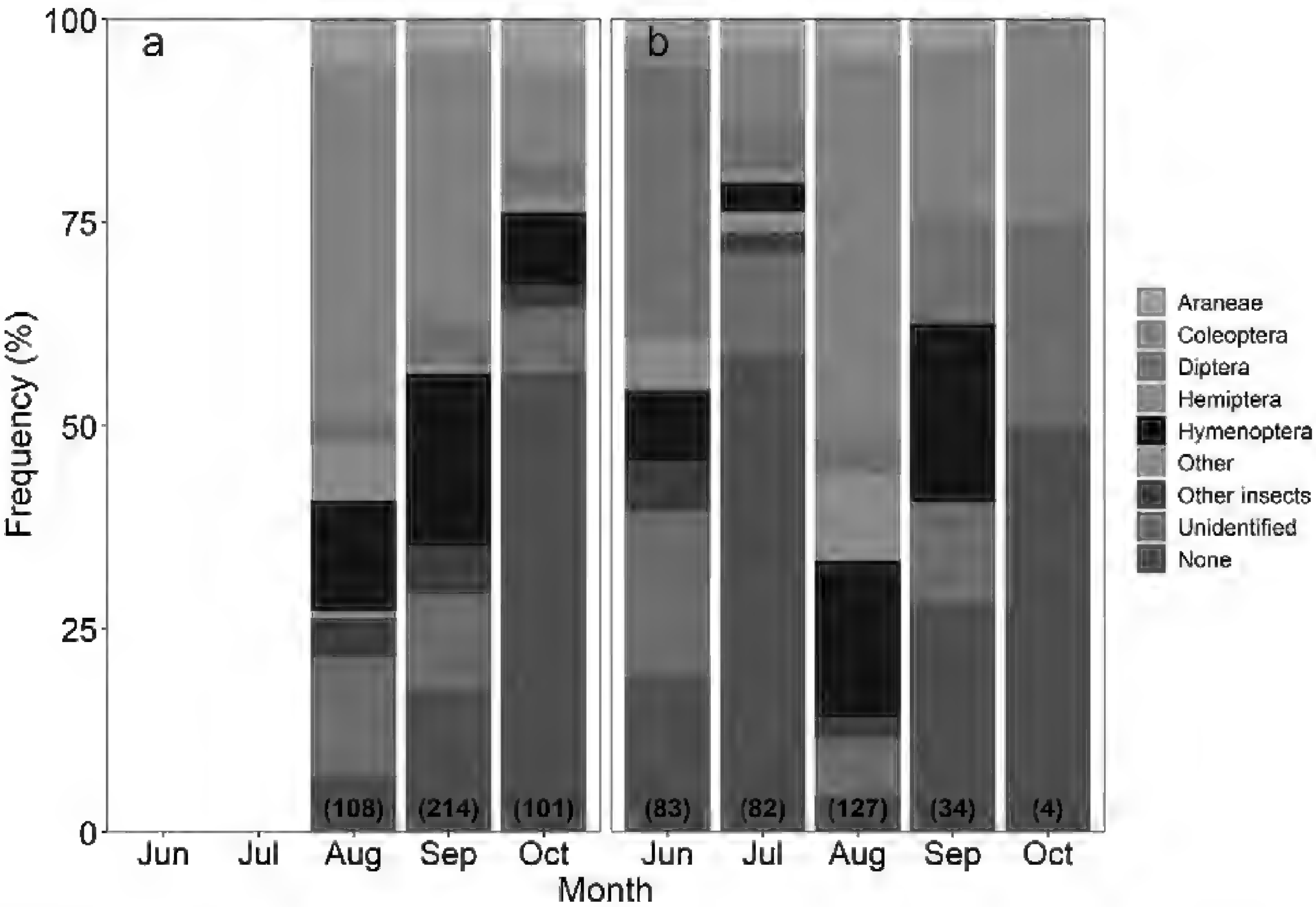


FIGURE 5. Frequency of prey categories by sampling month found in the stomach contents of a. young-of-the-year and b. ≥1 year classes of Carmine Shiner (*Notropis percobromus*) in the Birch River, Manitoba, Canada ($n = 514$). "Other insects" represents those that could not be classified to order, "Unidentified" is particles that could not be identified because of the high rate of digestion, and "None" indicates empty stomachs.

Evans 2014) probably explains their high proportions in shiner stomachs.

Diet patterns observed in our study were consistent with Carmine Shiner diet reported in the literature. Southern populations of Carmine Shiner in the Ozarks have been described as omnivorous, lower to mid-level consumers (Hoover 1989). Aquatic insects, particularly caddisfly larvae, constituted the bulk of the diet of these fishes, but they also consumed terrestrial insects, fish eggs, algae, diatoms, and inorganic material. Competition for prey among minnow species in an Ozark stream led to greater dietary specialization by Carmine Shiner on chironomids (Hoover 1989). The diversity in Carmine Shiner diet decreased in the

presence of Smallmouth Bass (*Micropterus dolomieu*) and increased with light levels, which suggests that prey are located by sight (Hoover 1989). Similarly, in the Whitemouth and Birch rivers in Manitoba, surface insects seem to be the dominant food type and Carmine Shiner have been observed rising to the surface to feed (K.W. Stewart pers. obs. 2006).

In our study, prey condition varied widely among individual fish and with prey type, and unidentifiable organic matter was a significant component of stomach contents, perhaps because digestion had continued after the fish were collected and preserved. Consequently, only a portion of the diet could be described and quantified based on intact prey. Identified Coleoptera remains consisted mainly of wings and the exoskeleton, indicating that the exoskeleton and especially the chelae may remain undigested for a long time. Other coleopteran body parts and other insects may be digested more rapidly, suggesting that the observed diet composition might partly reflect differences in food digestion.

Food availability may also have been affected by drought conditions in the summer of 2011, when water level dropped to an extremely low level. The occurrence of stagnant water and high water temperatures may have affected the abundance and distribution of prey items and, consequently, the availability of food for Carmine Shiners, thus explaining the high proportion of terrestrial prey in stomach contents.

Acknowledgements

This research was supported by funding from the Species at Risk program of Fisheries and Oceans Canada. Jon Svendsen, Elliot MacDonald, Wesley Donaldson, and Jeff Long assisted with fish collection. Thanks also to Zach Polk for assistance with the stomach content analysis and to Ken Stewart (Biological Sciences, University of Manitoba) for sharing his observations of surface feeding. We thank Dwayne Lepitzki, François Chapleau, and two anonymous reviewers for their constructive feedback on the manuscript. The data that support the findings of this study are available on the Canadian Open Government Data Portal.

Literature Cited

Borror, D.J., and R.E. White. 1970. A Field Guide to Insects. Houghton Mifflin Company, Boston, Massachusetts, USA.

Borror, D.J., and R.E. White. 1998. The Peterson Field Guides. Insects. Houghton Mifflin Harcourt, Boston, Massachusetts, USA.

Carr, M., D.A. Watkinson, J.C. Svendsen, E.C. Enders, J. Long, and K.-E. Lindenschmidt. 2015. Geospatial modeling of the Birch River: distribution of Carmine Shiner (*Notropis percobromus*) in geomorphic response units (GRU). International Review of Hydrobiology 100: 129–140. https://doi.org/10.1002/iroh.201501789

Clarke, D. 1998. Birch River watershed baseline study. M.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, Canada. Accessed 6 March 2020. http://www.nlc-bnc.ca/obj/s4/f2/dsk2/ftp01/MQ35056.pdf.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2018. COSEWIC assessment and update status report on the Carmine Shiner *Notropis percobromus* in Canada. COSEWIC, Ottawa, Ontario, Canada.

Evans, A.V. 2014. Beetles of Eastern North America. Princeton University Press, Princeton, New Jersey, USA.

Fisheries and Oceans Canada. 2013. Recovery strategy for the Carmine Shiner (*Notropis percobromus*) in Canada. Species at Risk Act recovery strategy series. Fisheries and Oceans Canada, Ottawa, Ontario, Canada. Accessed 6 March 2020. https://www.sararegistry.gc.ca/virtual_sara/files/plans/rs_tete_carminee_carmine_shiner_1013c_e.pdf.

Fisheries and Oceans Canada. 2015. Report on the progress of recovery strategy implementation for the Carmine Shiner (*Notropis percobromus*) in Canada for the period 2008–2013. Species at Risk Act recovery strategy report series. Fisheries and Oceans Canada, Ottawa, Ontario, Canada. Accessed 6 March 2020. https://www.sararegistry.gc.ca/virtual_sara/files/Pr-CarmineShinerv01-2015Jul13-eng.pdf.

Hoover, J.J. 1989. Trophic dynamics in an assemblage of Ozark stream fishes. Dissertation Abstracts International Part B, Sciences and Engineering 49: 95.

Macnaughton, C.J., C. Kovachik, and E.C. Enders. 2019. Standard metabolic rate models for Carmine Shiner (*Notropis percobromus*) and Common Shiner (*Luxilus cornutus*) across different temperature regimes. Journal of Fish Biology 94: 113–121. https://doi.org/10.1111/jfb.13869

Marshall, S.A. 2013. Insects: Their Natural History and Diversity. Firefly Books Ltd., Richmond Hill, Ontario, Canada.

Merritt, R.W., and K.W. Cummins. 1996. An Introduction to the Aquatic Insects of North America. Kendall Hunt Publishing Company, Dubuque, Iowa, USA.

R Core Team. 2017. R: a Language and Environment for Statistical Computing. Vienna, Austria.

Rennie, M.D., P.J. Kennedy, K.H. Mills, C.M.C. Rodgers, C. Charles, L.E. Hrenchuk, S. Chalanchuk, P.J. Blanchfield, M.J. Paterson, and C.L. Podemski. 2019. Impacts of freshwater aquaculture on fish communities: a whole-ecosystem experimental approach. Freshwater Biology 64: 870–885. https://doi.org/10.1111/fwb.13269

SARA (*Species at Risk Act*) Registry. 2019. Species profile: Carmine Shiner (*Notropis percobromus*). Accessed 13 April 2020. https://species-registry.canada.ca/index-en.html#/species/112-19.

Schoener, T.W. 1970. Nonsynchronous spatial overlap of lizards in patchy habitats. Ecology 51: 408–418. https://doi.org/10.2307/1935376

Stewart, K.W., and D.A. Watkinson. 2007. The Freshwater Fishes of Manitoba. University of Manitoba Press, Winnipeg, Manitoba, Canada.

Stol, J.A., J.C. Svendsen, and E.C. Enders. 2013. Determining the thermal preferences of Carmine Shiner (*Notropis percobromus*) and Lake Sturgeon (*Acipenser fulvescens*) using an automated shuttlebox. Canadian technical report of Fisheries and Aquatic Sciences 3038. Freshwater Institute, Fisheries and Oceans Canada, Winnipeg, Manitoba, Canada. Accessed 6 March 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/348161.pdf.

Visser, I., and M. Speekenbrink. 2010. depmixS4: an R package for hidden Markov Models. Journal of Statistical Software 36: 1–21. Accessed 20 April 2020. https://core.ac.uk/download/pdf/23798515.pdf.

Watkinson, D.A., and C.D. Sawatzky. 2013. Information in support of a recovery potential assessment of Carmine Shiner (*Notropis percobromus*). Research document 2013/014. Freshwater Institute, Fisheries and Oceans Canada, Winnipeg, Manitoba, Canada. Accessed 6 March 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/348715.pdf.

Received 5 July 2019
Accepted 11 March 2020

The Canadian Field-Naturalist

Tribute to "The Snake Man", Francis Russell Cook, Ph.D., C.M. (1935–2020)

Daniel F. Brunton[1,*], Paul M. Catling[2,*], and Brenda Kostiuk[2,*]

[1] Beaty Centre for Species Discovery and Botany Section, Canadian Museum of Nature, Ottawa, Ontario K1P 6P4 Canada
[2] 170 Sandford Avenue, Ottawa, Ontario K2C 0E9 Canada
[*] Corresponding authors: dbrunton@nature.ca; brenda.kostiuk@gmail.com

Brunton, D.F., P.M. Catling, and B. Kostiuk. 2020. Tribute to "The Snake Man", Francis Russell Cook, Ph.D., C.M. (1935–2020). Canadian Field-Naturalist 134(1): 71–84. https://doi.org/10.22621/cfn.v134i1.2577

The thundering, no-holds-barred belly-laugh was often what visitors first heard when entering the herpetology collection at the National Museum of Canada (NMC), now the Canadian Museum of Nature (CMN)—hereafter, "the Museum". That ringing welcome was from a man who not only sounded like Santa Claus but could easily have been his slimmed-down double, twinkling eyes and all. Indeed, one winter's day in a suburban mall, he was actually identified by an excited little boy as being the grand old man himself in civilian clothes (Frank Pope pers. comm. 15 June 2020). This jovial personality was especially appreciated during the time (1964–1993) when the collection and its associated offices were housed in mundane, rented commercial space in west end Ottawa, Ontario (ON) before they were transferred to the magnificent Natural Heritage Campus in Gatineau, Quebec (QC). Much more than just the laugh of this life-long herpetologist and long-time *Canadian Field-Naturalist* (CFN) editor was larger than life, however.

Francis Russell Cook (3 March 1935–3 January 2020), was one of those fortunate people who very early in life knew what he wanted to do, got to do it, and never regretted his choice. His passion for the study of amphibians and reptiles began in childhood and before he was through he had generated and analyzed a huge quantity of herpetological data (see Appendix 1), encouraged and inspired the research and careers of numerous biological investigators, and in his capacity as the longest serving Editor / Editor-in-Chief in this journal's 140 year history, facilitated the publication of a vast amount of scientific literature (Catling *et al.* 2016).

While proud of his Maritimes roots, Francis spent most of his life in Ontario. Upon arriving in Ottawa at 15 years of age he immediately began to expand his herpetological knowledge first through field experience and by connections with other naturalists in the local young naturalists' club (Cook 2010a). A decade later he was appointed Curator of Herpetology, thus commencing a 60-year professional herpetological association with the Museum. He would hold that position until 1991. Subsequently he continued to work almost daily as a Researcher Emeritus / Research Associate for another decade and a half (Figure 1) until illness confined him to his rural heritage stone home in the country near Bishops Mills, ON. Francis died in Kemptville, ON on 3 January 2020 after a short period of hospitalization (OFNC Publications Committee 2019). His happy laugh and twinkling smile were with him to the end.

Early History and Family

Francis was born in Wolfville, Nova Scotia (NS) on 3 March 1935. His father, Thomas William Cook, was a Professor of Psychology and also worked at the Defence Research Board in Ottawa, ON. Thomas' wife Dorothy (Cochrane) was a stay-at-home mother, looking after the home as well as son Francis, his brother Edmund Cochrane (Ned) Cook, and sister Florence Hazel (Smallman). The family moved considerably across Canada as required by Thomas' academic and professional appointments, residing for periods in Wolfville, NS; then Toronto, ON; Saskatoon, Saskatchewan; Victoria, British Columbia; and, finally, Ottawa.

Francis' curiosity in nature was piqued early (at age six!) when his brother, Ned hatched "a scoop of toad eggs" (Cook 2010a). He later visited the Royal Ontario Museum in Toronto and was so intrigued by what he saw and by the encouragement of legendary herpetologist Shelley Logier, that he decided then and there—at age nine—to dedicate his career to studying reptiles and amphibians. In Ottawa as a teenager

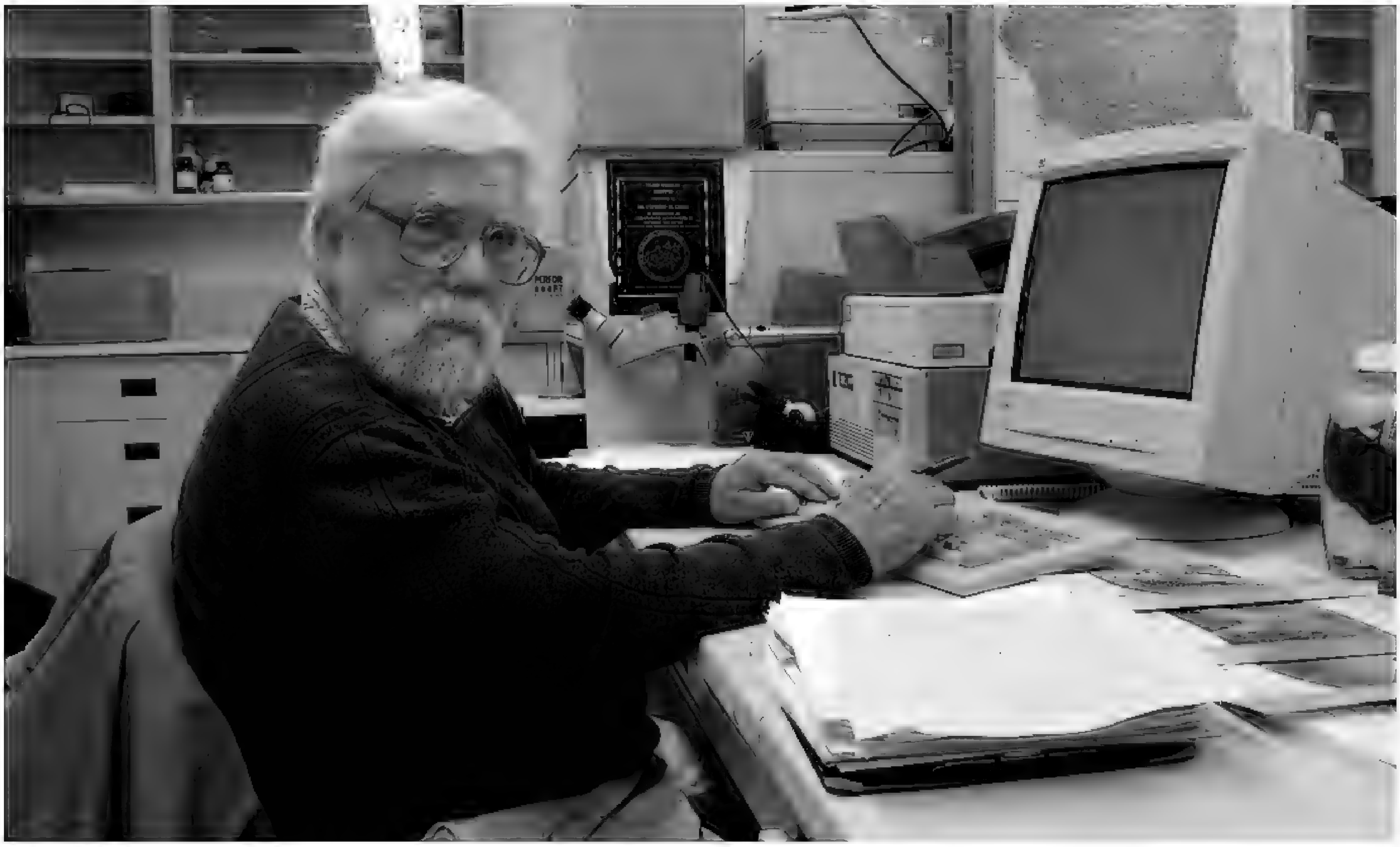


FIGURE 1. Francis Cook at his desk as Canadian Museum of Nature Emeritus Researcher, striking an atypically serious tone. Photo: Peter Frank, 11 September 2007, © Canadian Museum of Nature.

in 1950, he joined the Macoun Field Club (MFC), the junior naturalists' group co-sponsored by the Ottawa Field Naturalists' Club (OFNC) and the Museum, and soon became a volunteer leader. In later years as a Museum staff member he would serve as a leader of the program.

During an era when institutional facilities and their staff were substantially more publicly accessible than now, Francis also frequented the Museum herpetology section where he made a friend—and mentor—of fellow Nova Scotian, Dr. Sherman Bleakney. Francis assisted in Bleakney's research for several years, first as a volunteer and then as a summer field assistant. He then attended Acadia University (1955–1960), completing his B.Sc. in 1959, the same year that Bleakney moved from the Museum to Acadia University as well. Francis completed his M.Sc. there in 1960 under Bleakney's supervision, his thesis on the herptofauna of Prince Edward Island being based substantially on specimens they collected together. Ironically, considering their long history of joint field studies, research and collaboration (Figure 2), Bleakney died only two months before Francis (Bleakney 2020).

Francis married Joyce Crosby on 26 October 1962, an accomplished entomologist in her own right. In 1970 they purchased an old stone farmhouse south of Ottawa near Bishops Mills, ON, where the family (including son Thomas and daughter Wanda) lived in a quiet and beautifully wild setting.

Herpetological Research, Curation, and Teaching

Sherman Bleakney's return to Acadia University in 1958 had left the Museum without a staff herpetologist but Francis Cook was known to Museum personnel as an enthusiastic and knowledgeable—and unemployed—young man. When the offer was made in May 1960, he readily accepted the position as Curator of Herpetology. He held that post continuously thereafter except for a two-year educational leave in the late 1960s to do a Ph.D. (formally completed in 1978)

FIGURE 2. Francis Cook (far right) examining specimens in the field in eastern Ontario with Sherman Bleakney (left) and two unknown associates, August 1957. Photo: courtesy of Joyce Cook.

at the University of Manitoba in Winnipeg, Manitoba.

The early focus of his research at the Museum stemmed from his Ph.D. work, addressing the biogeographic and taxonomic implications of the transition zone between eastern and prairie biota as expressed through morphological variations in the native toads, Eastern American Toad (*Anaxyrus americanus americanus*) and Canadian Toad (now *Anaxyrus hemiophrys*). A life-long advocate for properly collected and suitably curated specimens, he collected the majority of the more than 4000 study specimens from between the Rocky Mountains and the Atlantic Ocean.

From his earliest days at the Museum Francis actively encouraged and facilitated contributions to the herpetological specimen collection and provided advice and collecting materials to willing field naturalists (including D.F.B. and P.M.C.) to ensure specimen contributions were responsibly obtained and that they maximized their information potential. Herpetologist Fred Schueler, later a Research Associate at the Museum, responded most prolifically to this encouragement and donated thousands of specimens, particularly those of Northern Leopard Frog (*Lithobates pipiens*). As curator of the collection until 1991, Francis oversaw its growth from an initial 14 000 to 133 000 specimens. It became the largest assemblage of Canadian herpetological material anywhere in the world (Cook 2010a).

Francis' research was always substantially field oriented, such as surveys of species distributional gaps across Canada, life history investigations of rare or biogeographically significant species, and inventories of national parks. This is reflected in his publications. Of the ~50 articles and notes he produced in peer-reviewed journals and the ~30 published elsewhere (Cook 2010a; Seburn and Halliday 2018), most address distributional issues or provide life history information for particular Canadian species. He proposed no nomenclatural innovations, although taxonomic implications were discussed in his comprehensive toad studies (Cook 1983).

Certainly one of the best known and appreciated of his publications is *Introduction to Canadian Amphibians and Reptiles* (Cook 1984) which is still in wide use. He was working on an update of that book as recently as 2018 (Spears 2018). On a more local level, his *Amphibians and Reptiles of Ottawa* (Cook 1981) remains the definitive herpetological treatment for that area.

Since the early 1970s Francis and Joyce Cook also conducted herpetological (and entomological) monitoring studies in the woods and wetlands surrounding their rural home. These investigations include the marking and release of over 28 000 amphibians and reptiles (Cook 2010a) in what surely must be one of the most comprehensive, long-term herpetological monitoring projects ever conducted in Canada. Although unpublished, these herpetological data are preserved in Museum files and are potentially available for analysis and documentation by others.

Francis' formal career at the Museum ended abruptly in July 1993 when several dozen researchers were summarily "retired" in a highly controversial and widely denounced cost-cutting measure (Mackenzie 1993). Remarkably, despite his bitterness at this forced retirement, he continued his Museum research without interruption. In January 1994 he accepted the honourary title of Curator / Researcher Emeritus and continued his work at the Museum as a Research Associate until only a couple of years ago, making the long drive into the Museum from the Land O'Nod Road (the euphonically appropriate address of his country home) on an almost daily basis.

Both in his research and general conversation Francis demonstrated a quick wit, a competitive nature, and a refreshing direct, honest manner. He could be feisty, showing particularly limited patience for byzantine bureaucracy. For Francis, however, the bottom line was one's level of commitment to the study of nature. If you had a passion for the investigation and conservation of the natural world, he had all the time in the world for you, regardless of your formal status. And you needed 'all the time in the world' too, because the man could talk! Visits or telephone conversations with Francis (he was constantly taking calls; Figure 3) were fascinating, informative, challenging … and never brief.

He was, simply put, inspirational and generous to a fault with his time and material. He and Joyce were amongst the longest serving members of the OFNC (over 60 years). Francis was a member of Council (the Board of Directors) from 1961 to 1966 and again from 1982 to 2011. He served one term as OFNC Vice-President (1965–1966) and was Chairman of the Macoun Field Club from 1961 to 1963. Such commitments cut into his professional productivity but he thought of this as a worthwhile contribution to Canadian natural sciences—and to naturalists. B.K., D.F.B., and P.M.C. are amongst the many, ranging from OFNC / MFC members and professional associates to citizens at large, who benefitted directly from his encouragement and aid. Many significant Canadian biological professionals would readily acknowledge the importance of Francis' mentorship in their early development.

Editorial Work

Francis was widely respected for his editorial work. Most of this involved CFN which he served in various capacities for 55 years. He was a member

FIGURE 3. A classic image of "the Snake Man" (as he was identified in the accompanying article), reptiles in one hand, phone in the other. The darker animal is a Northern Watersnake (*Nerodia sipedon*), the lighter one an Eastern Fox Snake (*Pantherophis gloydi*). Photo: scan of photo from Ottawa Citizen, 6 March 1987.

of the OFNC Publications Committee (CFN's publisher) from 1962 to 1966, and again from 1981 to 2010, where his influence was substantial. Most significant, however, was his unequalled editorial contribution. He served as an Associate Editor with prime responsibility for herpetology from 1972 to 1981 and again, with prime responsibility for herpetology and tributes, from 2011 to 2016. He was Editor-in-Chief from 1962 to 1966 and again from 1981 to 2010, a length of service (34 years), unmatched by any other editor in the journal's 140 year history (Brunton 1986; Cook 1986; Catling *et al.* 2016).

Francis was a careful and thoughtful editor who prided himself in helping struggling authors. He put 'getting it right' ahead of 'getting it quickly', to the frustration at times of associates and the journal's administration. It also led to an amusing line in his obituary from his son Thomas, however: "always a touch backlogged with his projects, Francis postponed publication of his obituary as long as he could before the accumulation of aging's downsides finally overcame his constitution" (Anonymous 2020).

Productivity and statistics

Francis oversaw the publication of an astonishing 19 275 pages in 35 volumes during his tenure as Editor/ Editor-in-Chief of CFN. This does not account for additional editorial work such as annotation and revision of manuscripts that were submitted to the journal but ultimately not published. That duration and those statistics fall short of telling the whole story, however. Successful peer review in scientific journals substantially relies on the expertise and good judgement of the editor(s), who must ultimately decide if and when a paper is ready for publication. Francis combined his skills as a field biologist with a usually patient editorial disposition that maximized the outcome for many authors. Much time was spent helping authors conceptualize their ideas and communicate effectively. This and his exceptional diligence encouraged the development of a strong and committed editorial and production team that remained largely intact for decades. Francis had a particularly strong and productive relationship with CFN Business Manager W.J. (Bill) Cody. Bill pursued his work on behalf of the publication with a comparable level of diligence for over 50 years (Catling *et al.* 2010; Cook 2010b).

A guiding concept

Francis strongly believed in and advocated for an independent Canadian journal of natural history to serve naturalists, conservationists, and scientists. He believed it could only be supported in Canada by subscriptions from both lay naturalists and employed professionals. Neither group alone would be strong enough to finance and sustain the preparation and production of such a peer-reviewed journal. This idea, in keeping with the OFNC's long-established mandate for encouraging and publishing original research by its members (Whyte 1880), has proven extremely successful over the years. On several occasions over the more than 135 years since the incorporation of the OFNC, bad times for the journal (e.g., World War I) were only survived with the support of the OFNC organization and bad times for the organization (e.g., the Great Depression) were only endured by national support through the journal (Brunton 2004).

Francis contributed to the protection of this inclusive concept with the *ad hoc* Publications Review Committee, appointed by the OFNC council. In 1980 and 1981 the committee reviewed and refined the editorial mandate and developed a policy to guide the proportion of scientific versus popular content in the

journal. This was not an easy nor an uncontroversial discussion. Although for diametrically opposite reasons, individuals at both extremes of the issue wanted to separate the journal from the OFNC (Smith 1981). After extensive consultation and debate, however, the unified philosophy prevailed, as indicated in the subsequent Publication Policy (Bedford 1983) which continues to frame and direct OFNC publications in the present. The success of this concept was due in substantial part to constructive input and a vigourous defence of that philosophy by Francis and other like-minded naturalists.

CFN as a tool for conservation

With the help of the federal Fisheries and Oceans Canada department (specifically, Robert Campbell; Renaud 2011) and personnel in the Canadian Wildlife Service (CWS), Francis arranged for the publication of a large series of status reports on faunal species at risk commissioned by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). These included annual reports, updates and—most importantly—status reports on 89 fishes and 51 marine mammal species. In addition, CFN published status reports on one amphibian, two reptiles, two birds, two mammals, one invertebrate, and 12 vascular plant species. This not only provided a significant public outlet for these important conservation documents when none other was available, but the associated publication fees represented significant financial relief for the operational costs of the CFN. Although federal and provincial governments eventually took over the online publication of official status reports, the CFN initiative had satisfied an important national conservation need (Lepitzki 2017) and continues to publish papers resulting from field work conducted during COSEWIC status report preparation (e.g., Ovaska *et al.* 2019).

Francis' conservation efforts also extended to his long-time (1981 to 1994) chairmanship of the COSEWIC Amphibian and Reptiles Subcommittee, and acting as Scientific Advisor from 1975 to 1994 on policy and regulation development for the Canadian representatives to the Convention on International Trade in Endangered Species (CITES).

Special issues

Themed issues exploring a particularly large and important topic area have been a part of CFN for many years, the first biological example being a catalogue of Saskatchewan birds published almost a century ago (Mitchell 1924). Francis promoted such comprehensive contributions more aggressively than any editor before him, resulting in some remarkable issues that not only contribute to the overall richness of the journal but are important as stand-alone publications. The first of these, "Peregrene <sic> Falcons in the 1980s" (CFN 104[2] 1990 https://www.biodiversitylibrary.org/page/34346719), represented the work of a number of contributors updating a continental assessment of this species at risk that had been published a decade earlier. A diversity of special issues subjects followed, including a valuable history of botanical exploration in Canada (Pringle 1995), the definitive biography of eminent Canadian ornithologist Percy A. Taverner (Cranmer-Byng 1996), the detailed description of orchid species in the Ottawa District of ON and QC (Reddoch and Reddoch 1997), and a comprehensive history of the CWS (Burnett 1999). Francis prepared a postscript for the latter, addressing the close working relationship between CFN and the CWS and pointing out that two of his predecessors as CFN editors were CWS scientists (Cook 1999).

Awards

Francis was sensitive and thoughtful in handling reptiles and amphibians, and a very supportive member of the Canadian Amphibian and Reptile Conservation Society. In 1991 he was the first recipient of the society's Distinguished Canadian Herpetologist Award (later renamed the R.W. Rankin Award) for his dedicated and long-term service.

Other career achievement recognition came with his receipt of the Alliance of Canadian Natural History Museum's first Gold Leaf Award (subsequently, the Naylor Award) in 2007 for "exceptional contribution to museum-based natural history in Canada" (Cook 2010a: 10). That was followed by the first Blue Racer Award by the Canadian Amphibian and Reptile Conservation Network in 2001 "in recognition of long standing contributions to amphibian and reptile research and conservation in Canada" (Canadian Herpetological Society 2020).

Honorary Membership of the Ottawa Field-Naturalists' Club was conferred on Francis in 1998 for his contributions to herpetology, conservation, and especially for his editorial contributions to CFN (Darbyshire 1999). He received the OFNC Member of the Year Award in 1990 for his efforts in re-establishing the journal's intended publication schedule (Gummer 1991) and again in 2010 in recognition of his overall contributions to CFN. Part of the latter citation reads "he has maintained the CFN as the most scientifically important and visible aspect of the Club" (Allison *et al.* 2011: 184). He was indirectly responsible for the OFNC receiving the Richardson Natural History Education Award Trophy (for special contributions to natural history education) from Ontario Nature (formerly, Federation of Ontario Naturalists) in 1996 in recognition of the long-term contribution

and continuing success of CFN (Pope 1997; Catling *et al.* 2010).

The production of two CFN Special Issues (132[1] https://doi.org/10.22621/cfn.v132i1.2140 and 132[2] https://doi.org/10.22621/cfn.v132i2.2167) in 2018 represented only the second time an issue of the journal (let alone two) had been dedicated to an individual (Figure 4). The only previous example was the memorial issue dedicated to OFNC founder (and CFN-predecessor editor) James Fletcher published over a century earlier (in 1909; Ottawa Naturalist 22[10] https://www.biodiversitylibrary.org/page/5506754).

In 2018 after a lifetime of distinguished service to Canadians and Canada, Francis was admitted as a Member to the Order of Canada (Figure 5). The citation (Governor General of Canada 2018) notes his contributions as a scientist, his success in the publication of vast amounts of biological information, and his effective communication of an appreciation of amphibians and reptiles to Canadians at large. What a fitting exclamation point for a remarkable and life-long editor!

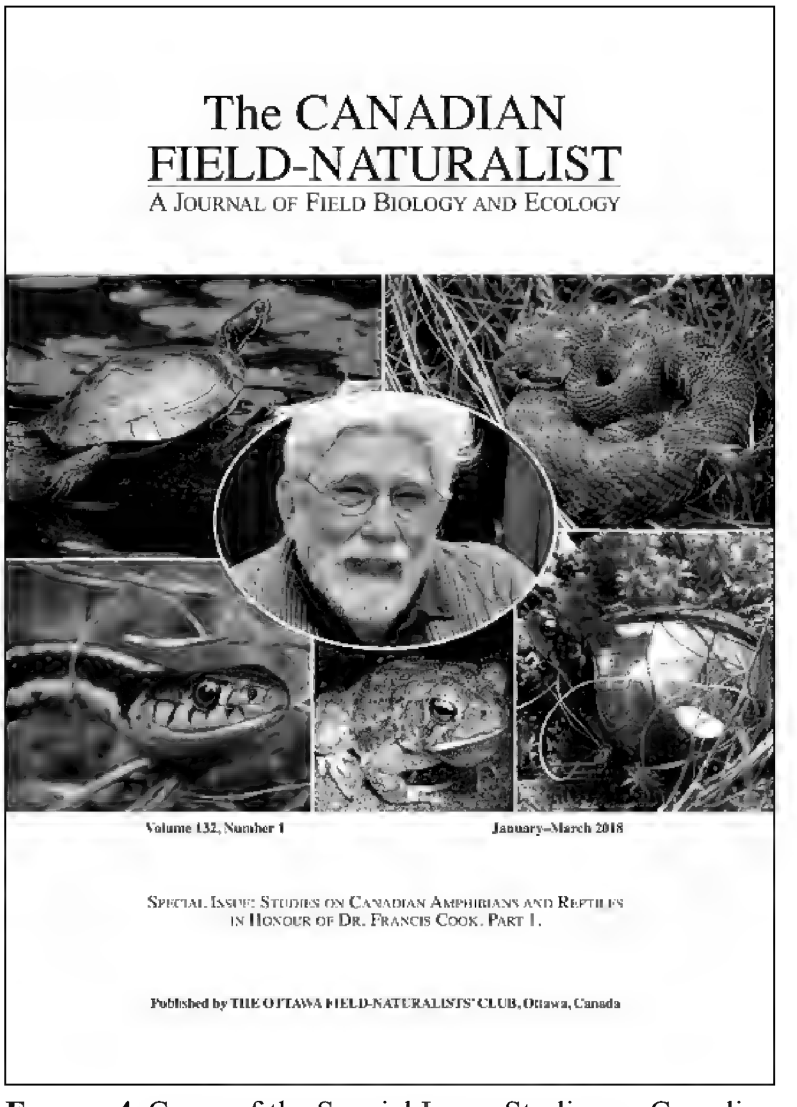


FIGURE 4. Cover of the Special Issue: Studies on Canadian Amphibians and Reptiles in Honour of Dr. Francis Cook, Part 1.

Always a Naturalist

Yes, Francis was a scientist but first and foremost, he was a classic field naturalist. To the end of his days he remained interested in promoting the publication of observational natural history investigation of all kinds and by all kinds of authors. Non-institutional contributors were welcome and, under his guidance, many independent and institutional researchers alike published the first of what would be a lifetime of scientific contributions in CFN. That noble achievement is perhaps his most greatly appreciated legacy. Of course, he will also be remembered as that surreal figure with twinkling eyes, a loud voice, and a quick wit.

Acknowledgements

We very much appreciate the help of Joyce Cook in providing information and illustrations for this tribute. In addition, the helpful suggestions by Francis' friend and Ottawa Field-Naturalists' Club publications associate E. Franklin Pope, are greatly appreciated. The comparably valuable input and perspective from long time Canadian Museum of Nature associate I.M. (Ernie) Brodo was also much appreciated. Similarly, we thank the Museum's Chantel Dussault and Christine Jenness for arranging access to and use of the Figure 1 image.

Literature Cited

Allison, K., I. Brodo, J. Cipriani, C. Hanrahan, and E. Zurbrigg. 2011. The Ottawa Field-Naturalists' Club Awards for 2010, presented April 2011. Francis Cook—Member of the Year. Canadian Field-Naturalist 125: 184–185. https://doi.org/10.22621/cfn.v125i2.1212

Anonymous. 2020. Francis Cook. Obituary, Ottawa Citizen, 6 January 2020. Accessed 23 June 2020. https://ottawacitizen.remembering.ca/obituary/francis-cook-1078206695.

Bedford, R.E. 1983. A publication policy for the Ottawa Field-Naturalists' Club. Canadian Field-Naturalist 97: 231–234. Accessed 23 June 2020. https://www.biodiversitylibrary.org/page/28008929.

Bleakney, P. 2020. Sherman Bleakney had an insatiable curiosity for all things that slithered and swam. The Globe and Mail, 17 March 2020. Accessed 11 June 2020. https://www.theglobeandmail.com/life/article-sherman-bleakney-had-an-insatiable-curiosity-for-all-things-that/.

Brunton, D.F. 1986. Additions to the documentation of the publication history of *The Canadian Field-Naturalist* and its predecessors. Canadian Field-Naturalist 100: 423–426. Accessed 23 June 2020. https://www.biodiversitylibrary.org/page/28072506.

Brunton, D.F. 2004. Origins and history of The Ottawa Field-Naturalists' Club. Canadian Field-Naturalist 118: 1–38. https://doi.org/10.22621/cfn.v118i1.879

Burnet, S. 1999. A passion for wildlife: a history of the Canadian Wildlife Service, 1947–1997. Canadian Field-Naturalist 113: 1–212. Accessed 23 June 2020. https://www.biodiversitylibrary.org/page/34234913.

Canadian Herpetological Society. 2020. Blue Racer Award Recipients. Accessed 23 June 2020. http://canadianherpetology.ca/about/awards/racer.html.

FIGURE 5. Francis Cook at the award ceremony of the Order of Canada at Rideau Hall on 1 February 2019 with Governor General Julie Payette (standing right). Photo: Sgt. Johanie Maheu, Rideau Hall © OSGG, 2019.

Catling, P.M., B. Bennett, G. Mitrow, F.R. Cook, and J. Cayouette. 2010. One step at a time … a tribute to William J. (Bill) Cody, 1922–2009. Canadian Field-Naturalist 124: 71–96. https://doi.org/10.22621/cfn.v124i1.1033

Catling, P.M., D.F. Brunton, J. Saarela, and F. Pope. 2016. Francis Cook steps down after long and distinguished service with the Ottawa Field-Naturalists' Club and the *Canadian Field-Naturalist*. Canadian Field-Naturalist 130: 385–387. https://doi.org/10.22621/cfn.v130i4.1944

Cook, F.R. 1981. Amphibians and Reptiles of the Ottawa District, revised edition. Trail & Landscape 15: 75–109. Accessed 23 June 2020. https://www.biodiversitylibrary.org/page/58418492.

Cook, F.R. 1983. An Analysis of Toads of *Bufo americanus* Group in a Contact Zone in Central Northern North America. National Museums of Canada Publications in Natural Sciences 3, Ottawa, Ontario, Canada.

Cook, F.R. 1984. Introduction to Canadian Amphibians and Reptiles. National Museum of Natural Sciences, Ottawa, Ontario, Canada.

Cook, F.R. 1986. The "one hundredth" volume of *The Canadian Field-Naturalist*. Canadian Field-Naturalist 100: 140–142. Accessed 23 June 2020. https://www.biodiversitylibrary.org/page/28072215.

Cook, F.R. 1999. Editor's Afterword. Canadian Field-Naturalist 113: 177. Accessed 23 June 2020. https://www.biodiversitylibrary.org/page/34235035.

Cook, F.R. 2010a. A recipe for a herpetologist: an autobiography. CAH/ACH Bulletin 18: 425.

Cook, F.R. 2010b. On missing Bill: recollections from 5 decades. Trail & Landscape 44: 59–61. Accessed 23 June 2020. https://www.biodiversitylibrary.org/page/59135165.

Darbyshire, S.J. 1999. The Ottawa Field-Naturalists' Club 1998 Awards. Canadian Field-Naturalist 113: 690–691. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/34235560.

Cranmer-Byng, J. 1996. A life with birds: Percy A. Taverner, Canadian Ornithologist 1875-1947. Canadian Field-Naturalist 110: 1–254. Accessed 23 June 2020. https://www.biodiversitylibrary.org/page/34342899.

Governor General of Canada. 2018. Order of Canada Appointments, June 29, 2018. Accessed 11 June 2020. https://www.gg.ca/en/media/news/2018/order-canada-appointments.

Gummer, B. 1991. Member of the year award: Francis R. Cook. Canadian Field-Naturalist 105: 579. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/34349097.

Lepitzki, D. 2017. Celebration of 40 years of COSEWIC and its close association with the Canadian Field-Naturalist. Canadian Field-Naturalist 131: 397. https://doi.org/10.22621/cfn.v131i4.2102

Mackenzie, D. 1993. Staff axed as leading museum goes down market. New Scientist 1891, 18 September 1993. Accessed 11 June 2020. https://www.newscientist.com/article/mg13918911-500-staff-axed-as-leading-museum-goes-down-market/.

Mitchell, H.H. 1924. Birds of Saskatchewan. Canadian

Field-Naturalist 38: 101–118. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/28021457.

OFNC (Ottawa Field-Naturalists' Club) Publications Committee. 2019. In memoriam: Francis Cook (3 March 1935–3 January 2020). Canadian Field-Naturalist 133: 297. https://doi.org/10.22621/cfn.v133i3.2473

Ovaska, K., L. Sopuck, and J. Heron. 2019. Surveys for terrestrial gastropods in the Kootenay region of British Columbia, with new records and range extensions. Canadian Field-Naturalist 133: 221–234. https://doi.org/10.22621/cfn.v133i3.2287

Pope, F. 1997. Richards Natural History Education Award. Trail & Landscape 31: 41–42.

Pringle, J.S. 1995. The history of the exploration of the vascular flora of Canada. Canadian Field-Naturalist 109: 291–356. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/35457143.

Reddoch, J.M., and A. Reddoch. 1997. The orchids in the Ottawa District: floristics, phytogeography, population studies and historical review. Canadian Field-Naturalist 111: 1–185. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/32418421.

Renaud, C.B. 2011. Robert (Bob) Ronald Campbell (1943–2011): biologist, conservationist, pastor. Canadian Field-Naturalist 125: 370–372. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/58249646.

Seburn, D.C., and W.D. Halliday. 2018. The publications of Francis Cook. Canadian Field-Naturalist 132: 99–102. https://doi.org/10.22621/cfn.v132i2.2169

Smith, L.C. 1981. Editor's farewell musings. Canadian Field-Naturalist 95: 233–235. Accessed 25 June 2020. https://www.biodiversitylibrary.org/page/28061936.

Spears, T. 2018. Order of Canada for Ottawa's go-to snake and frog expert. The Ottawa Citizen, July 6, 2018. Accessed 11 June 2020. https://ottawacitizen.com/news/local-news/order-of-canada-for-ottawas-go-to-snake-and-frog-expert.

Whyte, R.B. 1880. Annual Report. Transactions of the Ottawa Field-Naturalists Club 1: 7–11. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/12933453.

Received 23 June 2020
Accepted 2 July 2020

APPENDIX 1. Francis Cook publications.

A bibliography of the publications by Francis Cook was recently produced in this journal by Seburn and Halliday (2018) and thus is not repeated here. Amongst the titles they listed are all of Francis' publications in peer reviewed journals as well as herpetological publications in non-peer reviewed publications such as local naturalist club periodicals. These 101 titles may be accessed at https://doi.org/10.22621/cfn.v132i2.2169.

The following lists Francis Cook's 171 miscellaneous publications (thematically, in chronological order) which contain original information and are not included in Seburn and Halliday (2018). Francis also produced 32 annual Editor's Reports commencing with Cook (1982), each summarizing the journal's statistics for the proceeding volume. Those 'housekeeping' reports are not listed here.

This bibliography is presented in four subsections: listed first are abstracts, tributes, and historical publications, followed by important file reports, then book reviews in herpetology, and finally, other book reviews.

Literature Cited

Cook, F.R. 1982. Editor's report for 1981. Canadian Field-Naturalist 96: 220–223. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/28008068.

Seburn, D.C., and W.D. Halliday. 2018. The publications of Francis Cook. Canadian Field-Naturalist 132: 99–102. https://doi.org/10.22621/cfn.v132i2.2169

Bibliography

Abstracts, tributes, and history

Stewart, K.W., and F.R. Cook. 1970. [Abstract] Distribution of tree frogs of the *Hyla versicolor* complex in Manitoba. Pages 27–28 *in* American Society of Ichthyologists and Herpetologists Fifteenth Annual Meeting Abstracts. Tulane University, New Orleans, Louisiana, USA.

Cook, F.R. 1974. [Abstract] Zoogeography of amphibians and reptiles of western Canada. Program of 54th Annual Meeting of ASIH. NMNS. Abstracts page 4.

McAllister, D.E., and F.R. Cook. 1974. [Abstract] *Editors*: Program and Abstracts National Museum of Natural Sciences, Ottawa, Ontario, Canada.

Cook, F.R. 1984. [Tribute] Stanley W. Gorham. New Brunswick Naturalist 13(2): 49–52.

Cook, F.R., and D. Muir. 1984. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC): history and progress. Canadian Field-Naturalist 98: 63–70. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/28063890.

Cook, F.R. 1986a. The "one hundredth" volume of *The Canadian Field-Naturalist*. Canadian Field-Naturalist 100: 140–142. Accessed 23 June 2020. https://www.biodiversitylibrary.org/page/28072215.

Cook, F.R. 1986b. [Tribute] Addenda to tribute to Violet Humphreys 1919–1984. Canadian Field-Naturalist 100: 279. Accessed 25 June 2020. https://www.biodiversitylibrary.org/page/28072358.

Cook, F.R. 1987a. [Tribute] A continuing salute: William James Cody: managing *The Canadian Field-Naturalist*. Canadian Field-Naturalist 101: 159–160. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/28089584.

Cook, F.R. 1987b. [Tribute] Garrett C. Clough, 1932–1987. Canadian Field-Naturalist 101: 620. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/28090053.

Cook, F.R., and D.M. Green. 1987c. [Abstract] A reevaluation of the hybrid zone of two toad taxa (*Bufo*) in southeastern Manitoba: comparison of morphological and electrophoretic analysis. Program and Abstracts,

American Society of Ichthyologists and Herpetologists 67th Annual Meetings, 21–26 June 1987.

Cook, F.R., and W.E. Godfrey. 1988a. [Tribute] A Canadian bibliography of Austin L. Rand. Canadian Field-Naturalist 102: 567–571. Accessed 25 June 2020. https://www.biodiversitylibrary.org/page/28243840.

Cook, F.R. 1988b. [Abstract] The CURATOR program for herpetology at the National Museum of Natural Sciences. Program and Abstracts, American Society of Ichthyologists and Herpetologists, 68th Annual Meeting, Ann Arbor, Michigan, USA, 24–29 June 1988.

Cook, F.R. 1989a. [Abstract] Analysis of the northern Nearctic herpetofauna: distribution patterns and limits. Research Results Seminar, National Museum of Natural Sciences, 2–3 October 1989.

Cook, F.R. 1989b. [Abstract]. Postglacial herpetofaunas in the northern Nearctic: patterns and limits. *In* Symposium: biology of amphibians and reptiles of seasonally cold climates. Program and Abstracts, 69th Annual Meeting, American Society of Ichthyologists and Herpetologists, 17–23 June 1989. San Francisco State University and California Academy of Sciences, San Francisco, California, USA.

Cook, F.R. 1991a. [Tribute] William F. Davis, 1926–1991. Canadian Field-Naturalist 105: 414. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/34348928.

Cook, F.R. 1991b. [Tribute] A tribute to Stanley Warren Gorham 1917–1984. Canadian Field-Naturalist 105: 592–596. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/34349110.

Cook, F.R. 1991c. [Abstract]. Northern Nearctic herpetofauna at risk: COSEWIC from a zoogeographic perspective. Canadian Museum of Nature Research Results Conference, February 1991.

Cook, F.R. 1992. [Abstract] Frog flux: implications from two decades of monitoring a Gray Treefrog population in eastern Ontario. Canadian Museum of Nature 1992 Research Results Conference.

Gummer, B., and F.R. Cook. 1994. [Tribute] George Hazen McGee, 1909–1991. Canadian Field-Naturalist 108: 245–246. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/34263855.

Cook, F.R. 1995a. The Canadian Field-Naturalist: 114 years of publication on northern North American biodiversity. Global Biodiversity 5(1): 16–17.

Cook, F.R. 1995b. The Canadian Field-Naturalist: 115 years of publication on northern North American biodiversity—1880–1994. Amphipacifica 1(3): 75.

Cook, F.R. 1999. On the New Brunswick Museum. New Brunswick [St. John] Telegraph-Journal Tuesday 2 February 1999.

Cook. F.R. 2001a. [Abstract] Toward a history of 400 years of herpetological inventory and monitoring in Canada: I. Pre-Bleakney 1600–1950. II. Post-Bleakney 1960–2000. Invited Keynote Speaker with J. Sherman Bleakney in Special Session "A history of Canadian herpetology, with 'Father and Son' of modern Canadian Herpetology". Canadian Amphibian and Reptile Conservation Network Annual Meeting, Cornwall, Prince Edward Island, Canada, 20 October 2001.

Cook, F.R. 2001b. [Abstract] Another frog monitoring attempt: Big Rideau Lake *Rana* 1999–2000. Canadian Amphibian and Reptile Conservation Network Annual Meeting, Cornwall, Prince Edward Island, Canada, 20 October 2001.

Cook, F.R., and B.W. Coad. 2001. [Tribute] Donald Evan McAllister: curatorial and research contributions at the Canadian Museum of Nature. Sea Wind 15(2): 46–53.

Cook, F.R., C.G. Gruchy, and B.W. Coad. 2001. [Tribute] Donald Evan McAllister, 1934–2001: a tribute. Amphipacifica: Journal of Aquatic Systematic Biology 3(2): 1–2.

Cook, F.R. 2002. [two sidebar texts on D.E. McAllister] Page 10 *in* Some reflections on the life of Don E. McAllister *by* Ted Mosquin. Biodiversity 3(1): 7–10. https://doi.org/10.1080/14888386.2002.9712560

Cook, F.R., B.W. Coad, and C. Renaud. 2002. [Tribute] Donald Evan McAllister 1934–2001. Copeia 2002: 890–894. https://doi.org/10.1643/0045-8511(2002)002[0890:dem]2.0.co;2

Cook, F.R. 2006. Former CAH/ACH President Michael Rankin remembered [Tribute to R. Michael Rankin 1942–2006]. Canadian Association of Herpetologists Bulletin 14(2): 24–27.

Catling, P.M., B. Bennett, G. Mitrow, F.R. Cook, and J. Cayouette. 2010. [Tribute] One step at a time … a tribute to William J. (Bill) Cody, 1922–2009. Canadian Field-Naturalist 124: 71–96. https://doi.org/10.22621/cfn.v124i1.1033

Cook, F.R. 2010. [Tribute] On missing Bill: recollections from 5 decades. Trail & Landscape 44: 59–61. Accessed 24 June 2020. https://www.biodiversitylibrary.org/page/59135165.

Cook, F.R., B.W. Coad, C.B. Renaud, C.G. Gruchy, and N. Alfonso. 2010. [Tribute] Donald Evan McAllister, 1934-2001: the growth of ichthyological research at the National Museum of Canada/Canadian Museum of Nature. Canadian Field-Naturalist 124: 330–335. https://doi.org/10.22621/cfn.v124i4.1105

Cook, F.R., and E.L. Bousfield. 2012. [Tribute] A tribute to Charles Hogg Douglas, 1923–2004. Canadian Field-Naturalist 126: 164–166. https://doi.org/10.22621/cfn.v126i2.1335

Brodo, I., and F.R. Cook. 2012. [Tribute] A tribute to Phillip Merrill Youngman: 1927–2011. Canadian Field-Naturalist 126: 167–171. https://doi.org/10.22621/cfn.v126i2.1336

Cook, F.R. 2014a. [Tribute] Tribute to Kenneth Stewart, 1937–2011. Canadian Field-Naturalist 128: 84–90. https://doi.org/10.22621/cfn.v128i1.1527

Cook, F.R. 2014b. Retirement of Associate Editor C.D. Bird. Canadian Field-Naturalist 128: 218. https://doi.org/10.22621/cfn.v128i2.1575

Cook, F.R. 2014c. [Tribute] Obituary – Farley Mowat 1921–2014. Canadian Field-Naturalist 128: 219. https://doi.org/10.22621/cfn.v128i2.1575

Cook, F.R. 2014d. [Tribute] Tribute to Warren Baxter Ballard, 1947–2012. Canadian Field-Naturalist 128: 276–288. https://doi.org/10.22621/cfn.v128i3.1608

Cook, F.R. 2016. Roy John steps down after a distinguished contribution as Book Review Editor, Canadian Field-

Naturalist 130: 258–259. https://doi.org/10.22621/cfn.v130i3.1888

Wrigley, R.E., T.D. Galloway, J.R. Duncan, and F.R. Cook. 2016. [Tribute] A tribute to William Burton Preston, 1937–2013. Canadian Field-Naturalist 130: 355–358. https://doi.org/10.22621/cfn.v130i4.1931

Conlan, K.E., M.A. Bousfield, E.A. Hendrycks, E.L. Mills, F.R. Cook, and C.G. Gruchy. 2016. [Tribute] A tribute to Dr. Edward Lloyd Bousfield, 1926–2016. Canadian Field-Naturalist 130: 359–372. https://doi.org/10.22621/cfn.v130i4.1932

Catling, P.M., F. Cook, J. Saarela, W. Cotie, and F. Pope. 2017. [Tribute] Remembering Leslie Cody. Canadian Field-Naturalist 131: 95. https://doi.org/10.22621/cfn.v131i1.1968

Important file reports (available from Canadian Museum of Nature archives)

Cook, F.R. 1963. Report on spring herpetofaunal survey at Point Pelee National Park. National Parks Canada, Gatineau, Quebec.

Cook, F.R. 1968. Report on the joint National Museum of Canada–Institute of Jamaica Cooperative Field Program, July–August 1967. Submitted to the Director, National Museum of Canada and the Institute of Jamaica, Kingston, Jamaica.

Cook, F.R. 1971a. Preliminary reports on herpetofaunal surveys of five National Parks: Point Pelee, La Maurice, Forillon, Kouchibouquac, and Kejimkujik. Submitted to National Parks Canada, Gatineau, Quebec, Canada.

Cook, F.R. 1971b. Preliminary report: Herpetology surveys for national parks by National Museum of Natural Sciences 1971, Musée national des sciences naturelles, Ottawa.

Cook, F.R. 1974. Herpetology at the National Museum of Natural Sciences: a backward and forward look. Report submitted to the Chief Zoologist and the Director, National Museum of Natural Sciences.

Cook, F.R. 1980. Vertebrate surveys at the National Museum of Canada: a historical perspective. Unpublished manuscript for talk given at the Annual Meeting of the National Museum of Natural Sciences, 24 November 1980.

Cook, F.R. 1984a. Background information. Pages 8–16 *in* A herpetofaunal survey of Gatineau Park *by* I.T. McMurray. Ms. report. National Capital Commission March 1984. 5 Volumes.

Cook, F.R. 1984b. Foreword *in* Herpetology of the Tobermory Islands *by* F.W. Schueler. Ms. report. Parks Canada, Cornwall, Ontario, Canada.

Cook, F.R. 1984c. Preface. Pages i–iii *in* A herpetofaunal survey of Gatineau Park *by* I.T. McMurray. Ms. report. National Capital Commission March 1984. 5 Volumes.

Cook, F.R. 1987. Report of the Collection Policy Committee: The Management and Philosophy of Collections at the NMNS. Submitted to the Acting Assistant Director 18 August 1987.

Cook, F.R. 1991a. Endangered salamanders and the Seebe Leasehold. A Report to Lafarge Canada, Inc., July.

Cook, F.R. 1991b. The Herpetology Section at the Canadian Museum of Nature: procedures and history. Canadian Museum of Nature. Draft manuscript.

Cook, F.R. 1992. Foreword *in* Herpetology of Bruce Peninsula *by* F.W. Schueler. Ms. report to Canadian Parks Service.

Book reviews—herpetology

Cook, F.R. 1970a. [Book Review] A Field Guide to Western Reptiles and Amphibians. Canadian Field-Naturalist 84: 322–323. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/29553548.

Cook, F.R. 1970b. [Book Review] The World of the Frog and the Toad. Blue Jay 28: 96–97.

Cook, F.R. 1971a. [Book Review] A New Field Book of Reptiles and Amphibians. Canadian Field-Naturalist 85: 272–273. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28044703.

Cook, F.R. 1971b. [Book Review] The Amphibians and Reptiles of New Brunswick. Canadian Field-Naturalist 85: 273–274. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28044704.

Cook, F.R. 1974a. [Book Review] The Snakes of Canada. Canadian Field-Naturalist 88: 242–243. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28060847.

Cook, F.R. 1974b. [Book Review] Introduction to Herpetology. Canadian Field-Naturalist 88: 248–249. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28060853.

Cook, F.R. 1982a. [Book Review] Amphibians of Canada. Canadian Field-Naturalist 96: 373–374. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28060847.

Cook, F.R. 1982b. [Book Review] Snakes – a Natural History. Canadian Field-Naturalist 96: 498. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28008354.

Cook, F.R. 1982c. [Book Review] A Bibliography of Pacific Northwest Herpetology. Canadian Field-Naturalist 96: 498–499. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28008354.

Cook, F.R. 1984. [Book Review] Amphibians and Reptiles of New England: Habitats and Natural History. Canadian Field-Naturalist 98: 406–407. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28064241.

Cook, F.R. 1985a. [Book Review] A Guide to Field Identification Reptiles of North America. Canadian Field-Naturalist 99: 123–124. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28065136.

Cook, F.R. 1985b. [Book Review] Their Blood Runs Cold: Adventures with Reptiles and Amphibians. Canadian Field-Naturalist 99: 125. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28065138.

Cook, F.R. 1991a. [Book Review] Poisonous Snakes. Canadian Field-Naturalist 105: 444–445. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34348958.

Cook, F.R. 1991b. [Book Review] Living Snakes of the World in Colour. Canadian Field-Naturalist 105: 445–

446. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34348959.

Cook, F.R. 1991c. [Book Review] Advances in Herpetology and Evolutionary Biology. Canadian Field-Naturalist 105: 602. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34349120.

Cook, F.R. 1991d. [Book Review] Lizard Ecology: Studies of a Model Organism. Canadian Field-Naturalist 105: 603. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34349121.

Cook, F.R. 1991e. [Book Review] Field Guide to Amphibians and Reptiles of Eastern and Central North America. Third Edition. Canadian Field-Naturalist 105: 608–610. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34349126.

Cook, F.R. 1991f. [Book Review] Significant Trade in Wildlife: a Review of Selected Species in CITES Appendix II. Volume 2: Reptiles and Invertebrates. Canadian Field-Naturalist 105: 611–612. Accessed 4 July 2020. https://www.biodiversitylibrary.org/page/34349129.

Cook, F.R. 1991g. [Book Review] Ontario Herpetofaunal Summary, 1984, 1985, 1986. Canadian Field-Naturalist 105: 612–614. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34349130.

Cook, F.R. 1991h. [Book Review] Atlas des Amphibians et des Reptiles du Quebec 1988–89. Canadian Field-Naturalist 105: 614–615. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34349132.

Cook, F.R. 1992a. [Book Review] Peterson First Guide to Reptiles and Amphibians. Canadian Field-Naturalist 106: 545. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34347773.

Cook, F.R. 1992b. [Book Review] The Year of the Turtle. Nature Canada 21: 57, 61.

Cook, F.R. 1994. [Book Review] Amphibians and Reptiles of Alberta. Canadian Book Review Annual, entry 5017.

Cook, F.R. 1995a. [Book Review] The Amphibians and Reptiles of Maine. Canadian Field-Naturalist 109: 482–483. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35457338.

Cook, F.R. 1995b. [Book Review] Herpetology: an Introductory Biology of Amphibians and Reptiles. Canadian Field-Naturalist 109: 483–485. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35457339.

Cook, F.R. 1995c. [Book Review] Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Canadian Field-Naturalist 109: 488. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35457344.

Cook, F.R. 1995d. [Book Review] Atlas des Amphibians et des Reptiles du Quebec [1994]. Canadian Field-Naturalist 109: 493. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35457349.

Cook, F.R. 1995e. [Book Review] The Reptiles and Amphibians of the Hamilton Area: a Historical Summary and the Results of the Hamilton Herpetological Atlas. Canadian Field-Naturalist 109: 494–495. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35457350.

Cook, F.R. 1997a. [Book Review] Ecology and Conservation of Amphibians. Global Biodiversity 7: 44.

Cook, F.R. 1997b. [Book Review] The Garter Snakes: Evolution and Ecology. Blue Jay 55: 209–210.

Cook, F.R. 1997c. [Book Review] Amphibians of Oregon, Washington, and British Columbia: a Field Identification Guide. Canadian Field-Naturalist 111: 685. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35599590.

Cook, F.R. 1997d. [Book Review] Snakes in Question: the Smithsonian Answer Book. Canadian Field-Naturalist 111: 685–686. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35599590.

Cook, F.R. 1997e. [Book Review] Amphibian Biology. Volume 1. The Integument; Amphibian Biology. Volume 2. Social Behaviour. Canadian Field-Naturalist 111: 687–689. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35599592.

Cook, F.R. 1997f. [Book Review] Pleistocene Amphibians and Reptiles in North America. Canadian Field-Naturalist 111: 696–697. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35599601.

Cook, F.R. 1998a. [Book Review] Amphibians and Reptiles Native to Minnesota. Canadian Field-Naturalist 112: 170–171. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34257514.

Cook, F.R. 1998b. [Book Review] A Monograph of the Colubrid Snakes of the Genus *Elaphe* Fitzinger. Canadian Field-Naturalist 112: 171. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34257515.

Cook, F.R. 1998c. [Book Review] Reptiles and Amphibians of Prince Edward County. Canadian Field-Naturalist 112: 172–173. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34257516.

Cook, F.R. 1998d. [Book Review] A Natural History of Amphibians. Canadian Field-Naturalist 112: 374–375. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34257722.

Cook, F.R. 1999a. [Book Review] Reptiles and Amphibians of Prince Edward County, Ontario. Canadian Book Review Annual 23: 426.

Cook, F.R. 1999b. [Book Review] Herpetology. Canadian Field-Naturalist 113: 536. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34235402.

Cook, F.R. 1999c. [Book Review] Amphibians in Decline: Canadian Studies of a Global Problem. Canadian Field-Naturalist 113: 536–537. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34235403.

Cook, F.R. 1999d. [Book Review] Amphibians and Reptiles of the Great Lakes Region. Canadian Field-Naturalist 113: 539. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34235405.

Cook, F.R. 1999e. [Book Review] A Field Guide to the Life and Times of Roger Conant. Canadian Field-Naturalist 113: 554–553. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34235420

Cook, F.R. 1999f. [Book Review] Encyclopedia of Reptiles and Amphibians. Canadian Field-Naturalist 113: 700–701. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34235570.

Cook, F.R. 2001. [Book Review] Field Guide to Reptiles and Amphibians of Eastern and Central North America.

Expanded Third Edition. Canadian Field-Naturalist 115: 194. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34995264.

Cook, F.R. 2002a. [Book Review] The Royal Ontario Museum Field Guide to Amphibians and Reptiles of Ontario. Canadian Field-Naturalist 116: 653–654. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35151899.

Cook, F.R. 2002b. [Book Review] The Amphibians and Reptiles of Alberta: a Field Guide and Primer of Boreal Herpetology, Second Edition. Canadian Field-Naturalist 116: 654–655. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35151900.

Cook, F.R. 2002c. [Book Review] Rare Amphibians, Reptiles, and Mammals of British Columbia. Canadian Field-Naturalist 116: 655–656. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35151901.

Cook, F.R. 2002e. [Book Review] Scientific and Standard English Names of Amphibians and Reptiles of North America North of Mexico, with Comments Regarding Confidence in Our Understanding. Canadian Field-Naturalist 116: 656–658. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35151902.

Cook, F.R. 2002f. [Book Review] State and Provincial Amphibian and Reptile Publications for the United States and Canada. Canadian Field-Naturalist 116: 662. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35151908.

Cook, F.R. 2002g. [Book Review] Salamanders of the United States and Canada. Canadian Field-Naturalist 116: 663. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35151909.

Cook, F.R. 2002h. [Book Review] Patterns of Distribution of Amphibians: a Global Perspective. Canadian Field-Naturalist 116: 664. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35151910.

Cook, F.R. 2002i. [Book Review] The Amphibians of the Former Soviet Union. Canadian Field-Naturalist 116: 665–666. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35151911.

Cook, F.R. 2002j. [Book Review] The Atlas of the Amphibians and Reptiles of Vermont. Canadian Field-Naturalist 116: 666–667. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35151912.

Cook, F.R. 2002k. [Book Review] Snake. Canadian Field-Naturalist 116: 667–668. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35151913.

Cook, F.R. 2002L. [Book Review] A Field Guide to the Amphibians and Reptiles of the Maya World: the Lowlands of Mexico, Northern Guatemala, and Belize. Canadian Field-Naturalist 116: 668–669. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35151914.

Cook, F.R. 2003a. [Book Review] Reptiles and Amphibians of Algonquin Provincial Park. Canadian Field-Naturalist 117: 490–491. https://doi.org/10.22621/cfn.v117i3.757

Cook, F.R. 2003b. [Book Review] Herpetology in Montana: a History, Status Summary, Checklists, Dichotomous Keys, Accounts of Native, Potentially Native, and Exotic Species, and Indexed Bibliography. Canadian Field-Naturalist 117: 491–492. https://doi.org/10.22621/cfn.v117i3.758

Cook, F.R. 2003c. [Book Review] Guide to the Reptiles of the Eastern Palearctic. Canadian Field-Naturalist 117: 492. https://doi.org/10.22621/cfn.v117i3.759

Cook, F.R. 2003d. [Book Review] Herpetology: an Introductory Biology of Amphibians and Reptiles, Second Edition. Canadian Field-Naturalist 117: 493. https://doi.org/10.22621/cfn.v117i3.760

Cook, F.R. 2003e. [Book Review] In Quest of Great Lakes Ice Age Vertebrates. Canadian Field-Naturalist 117: 494. https://doi.org/10.22621/cfn.v117i3.761

Cook, F.R. 2003f. [Book Review] Snakes of the United States and Canada. Canadian Field-Naturalist 117: 495. https://doi.org/10.22621/cfn.v117i3.762

Cook, F.R. 2004a. [Book Review] Amphibian Decline: an Integrated Analysis of Multiple Stressor Effects. Canadian Field-Naturalist 118: 138. https://doi.org/10.22621/cfn.v118i1.838

Cook, F.R. 2004b. [Book Review] Lizards: Windows to the Evolution of Diversity. Canadian Field-Naturalist 118: 141–142. https://doi.org/10.22621/cfn.v118i1.860

Cook, F.R. 2004c. [Book Review] Canadian Skin and Scales: a Complete Encyclopedia of Canadian Amphibians and Reptiles. Canadian Field-Naturalist 118: 467–468. https://doi.org/10.22621/cfn.v118i3.32

Cook, F.R. 2005a. [Book Review] Amphibiens et Reptiles du Quebec et les Maritimes. Canadian Field-Naturalist 119: 141. https://doi.org/10.22621/cfn.v119i1.194

Cook, F.R. 2005b. [Book Review] Frogs of Australia: an Introduction to their Classification, Biology and Distribution. Canadian Field-Naturalist 119: 145. https://doi.org/10.22621/cfn.v119i1.199

Cook, F.R. 2005c. [Book Review] Venomous Reptiles of the Western Hemisphere. 2 Volumes. Canadian Field-Naturalist 119: 148–149. https://doi.org/10.22621/cfn.v119i1.204

Cook, F.R. 2007a. [Book Review] The Amphibians and Reptiles of British Columbia. Royal BC Museum Handbook, Victoria, British Columbia. Canadian Field-Naturalist 121: 100–101. https://doi.org/10.22621/cfn.v121i1.405

Cook, F.R. 2007b. [Book Review] Ecology and Evolution in the Tropics: a Herpetological Perspective. Canadian Field-Naturalist 121: 338. https://doi.org/10.22621/cfn.v121i3.457

Cook, F.R. 2007c. [Book Review] The Ecology and Behavior of Amphibians. Canadian Field-Naturalist 122: 439. https://doi.org/10.22621/cfn.v121i4.490

Cook, F.R. 2007d. [Book Review] Amphibians and Reptiles of New York State: Identification, Natural History, and Conservation. Canadian Field-Naturalist 121: 439–440. https://doi.org/10.22621/cfn.v121i4.491

Cook, F.R. 2007e. [Book Review] Reptiles and Amphibians of Canada. Canadian Field-Naturalist 121: 443–444. https://doi.org/10.22621/cfn.v121i4.495

Cook, F.R. 2007f. [Book Review] Guides and Reference to the (1) Amphibians, (2) Snakes, (3) Crocodilians, Turtles, and Lizards of Eastern and Central North America (North of Mexico). Canadian Field-Naturalist 121: 444. https://doi.org/10.22621/cfn.v121i4.496

Cook, F.R. 2007g. [Book Review] Contributions to the History of Herpetology, Volume 2. Canadian Field-Naturalist 121: 448. https://doi.org/10.22621/cfn.v121i4.501

Cook, F.R. 2008a. [Book Review] Frog. Canadian Field-Naturalist 122: 84–85. https://doi.org/10.22621/cfn.v122i1.529

Cook, F.R. 2008b. [Book Review] Rattlers, Peepers & Snappers. 2008. Canadian Field-Naturalist 122: 85. https://doi.org/10.22621/cfn.v122i1.530

Cook, F.R. 2008c. [Book Review] Scientific and Standard English Names of Amphibians and Reptiles of North America North of Mexico, with Comments Regarding Confidence in our Understanding. Sixth Edition. Canadian Field-Naturalist 122: 357–358. https://doi.org/10.22621/cfn.v122i4.620

Cook, F.R. 2009a. [Book Review] The Frogs and Toads of North America: a Comprehensive Guide to Their Identification, Behavior, and Calls. Canadian Field-Naturalist 123: 75–76. https://doi.org/10.22621/cfn.v123i1.649

Cook, F.R. 2009b. [Book Review] Amphibian Biology. Volume 8. Canadian Field-Naturalist 123: 378. https://doi.org/10.22621/cfn.v123i4.1013

Cook, F.R. 2009c. [Book Review] Frogs: Inside Their Remarkable World. Canadian Field-Naturalist 123: 379. https://doi.org/10.22621/cfn.v123i4.1014

Cook, F.R. 2009d. [Book Review] The Rise of Amphibians: 365 Million Years of Evolution. Canadian Field-Naturalist 123: 380. https://doi.org/10.22621/cfn.v123i4.1016

Cook, F.R. 2009e. [Book Review] Snakes: Ecology and Conservation. Canadian Field-Naturalist 123: 381. https://doi.org/10.22621/cfn.v123i4.1017

Cook, F.R. 2009f. [Book Review] Biological Notes on an Old Farm: Exploring Common Things in the Kingdoms of Life. Canadian Field-Naturalist 123: 388. https://doi.org/10.22621/cfn.v123i4.1023

Cook, F.R. 2010. [Book Review] Amphibian Ecology and Conservation: a Handbook of Techniques. Canadian Field-Naturalist 124: 69. https://doi.org/10.22621/cfn.v124i1.1043

Cook, F.R. 2012a. [Book Review] Scientific and Standard English Names of Amphibians and Reptiles of North America North of Mexico, with Comments Regarding Confidence in our Understanding. Seventh Edition. Canadian Field-Naturalist 126: 340–341. https://doi.org/10.22621/cfn.v126i4.1382

Cook, F.R. 2012b. [Book Review] Amphibian Biology. Volume 10. Conservation and Decline of Amphibians: Ecological Aspects, Effect of Humans, and Management. Canadian Field-Naturalist 126: 341–342. https://doi.org/10.22621/cfn.v126i4.1383

Cook, F.R. 2012c. [Book Review] The Amphibians and Reptiles of Michigan: a Quaternary and Recent Faunal Adventure. Canadian Field-Naturalist 126: 342–344. https://doi.org/10.22621/cfn.v126i4.1384

Cook, F.R. 2012d. [Book Review] Contributions to the History of Herpetology. Volume 3. Canadian Field-Naturalist 126: 344–345. https://doi.org/10.22621/cfn.v126i4.1385

Cook, F.R. 2012e. [Book Review] A Pocket Guide to Lizards and Turtles of Pennsylvania. Canadian Field-Naturalist 126: 345–346. https://doi.org/10.22621/cfn.v126i4.1386

Cook, F.R. 2013a. [Book Review] The Snakes of Ontario: Natural History, Distribution, and Status. Canadian Herpetologist 3: 11–13.

Cook, F.R. 2013b. [Book Review] The Eponym Dictionary of Amphibians. Canadian Field-Naturalist 127: 275–276. https://doi.org/10.22621/cfn.v123i4.1014

Cook, F.R. 2013c. [Book Review] Frogs of the United States and Canada (2 Volumes). Canadian Field-Naturalist 127: 366–367. https://doi.org/10.22621/cfn.v127i4.1499

Cook, F.R. 2014a. [Book Review] A Pocket Guide to Salamanders of Pennsylvania. Canadian Field-Naturalist 128: 95. https://doi.org/10.22621/cfn.v128i1.1531

Cook, F.R. 2014b. [Book Review] Amphibian Conservation – Global Evidence for the Effects of Interventions. Canadian Field-Naturalist 128: 416. https://doi.org/10.22621/cfn.v128i4.1640

Cook, F.R. 2014c. [Book Review] Amphibians and Reptiles in Minnesota. Canadian Field-Naturalist 128: 416–417. https://doi.org/10.22621/cfn.v128i4.1641

Cook, F.R. 2014d. [Book Review] Amphibians of Ohio. Canadian Field-Naturalist 128: 417–418. https://doi.org/10.22621/cfn.v128i4.1642

Cook, F.R. 2015. [Book Review] Amphibian Biology. Volume 11, Part 4: Status of Conservation and Decline of Amphibians: Eastern Hemisphere: Southern Europe and Turkey. Canadian Field-Naturalist 129: 97. https://doi.org/10.22621/cfn.v129i1.1675

Cook, F.R. 2016. [Book Review] Peterson Field Guide to Reptiles and Amphibians of Eastern and Central North America. Fourth Edition. Canadian Field-Naturalist 130: 374–375. https://doi.org/10.22621/cfn.v130i4.1936

Book reviews—other

Cook, F.R. 1962. [Book Review] Wildlife Sketches—Near and Far. Canadian Field-Naturalist 76: 170. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28112486.

Cook, F.R. 1963a. [Book Review] The Natural World of Louise Dickenson Rich. Canadian Field-Naturalist 77: 55. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28098824.

Cook, F.R. 1963b. [Book Review] Rascal: a Memoir of a Better Era. Canadian Field-Naturalist 77: 230. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28099011.

Cook, F.R. 1964a. [Book Review] A Sharing of Joy. Canadian Field-Naturalist 78: 58. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28020354.

Cook, F.R. 1964b. [Book Review] The Last Horizon. Canadian Field-Naturalist 78: 193. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28020497.

Cook, F.R. 1965a. [Book Review] The Fields of Noon. Canadian Field-Naturalist 79: 74. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28033558.

Cook, F.R. 1965b. [Book Review] The Pond. Canadian Field-Naturalist 79: 74. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28033558.

Cook, F.R. 1965c. [Book Review] Many Trails. Canadian Field-Naturalist 79: 74–75. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28033558.

Cook, F.R. 1986. [Book Review] How to Edit a Scientific Journal. Canadian Field-Naturalist 100: 455–456. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/28072538.

Cook, F.R. 1989. [Book Review] *Borealis*: a Magazine for Canadian Parks and Wilderness. Canadian Field-Naturalist 103: 298. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34348126.

Cook, F.R. 1995a. [Book Review] The Green Trees Beyond: a Memoir. Canadian Book Review Annual 1995: 65–66.

Cook, F.R. 1995b. [Book Review] Wetlands. Canadian Book Review Annual 1995: 402.

Cook, F.R. 1995c. [Book Review] *Cadborosaurus*: Survivor from the Deep. Canadian Field-Naturalist 109: 498–499. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35457354.

Cook, F.R. 1996. [Book Review] Last of the Curlews. Canadian Field-Naturalist 110: 373. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/34343275.

Cook, F.R. 1997a. [Book Review] Canada's Biodiversity: the Variety of Life, its Status, Economic Benefits, Conservation Costs and Unmet Needs. Recovery [Canadian Wildlife Service](Spring 1997): 11.

Cook, F.R. 1997b. [Book Review] American Museum of Natural History: 125 Years of Expedition and Discovery. Canadian Field-Naturalist 111: 710–711. Accessed 20 June 2020. https://www.biodiversitylibrary.org/page/35599615.

Cook, F.R. 2003. [Book Review] Farley: The Life of Farley Mowat. Canadian Field-Naturalist 117: 509–510. https://doi.org/10.22621/cfn.v117i3.778

Cook, F.R. 2005. [Book Review] The Nature Journal: a Handbook. Canadian Field-Naturalist 119: 154. https://doi.org/10.22621/cfn.v119i1.210

The Canadian Field-Naturalist

Book Reviews

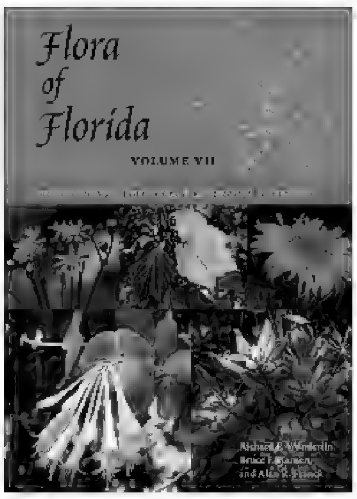
Book Review Editor's Note: *The Canadian Field-Naturalist* is a peer-reviewed scientific journal publishing papers on ecology, behaviour, taxonomy, conservation, and other topics relevant to Canadian natural history. In line with this mandate, we review books with a Canadian connection, including those on any species (native or non-native) that inhabits Canada, as well as books covering topics of global relevance, including climate change, biodiversity, species extinction, habitat loss, evolution, and field research experiences.

Currency Codes: CAD Canadian Dollars, USD United States Dollars, EUR Euros, AUD Australian Dollars, GBP British Pounds.

Botany

Flora of Florida, Volume VII: Dicotyledons, Orobanchaceae through Asteraceae

By Richard P. Wunderlin, Bruce F. Hansen, and Alan R. Franck. 2020. University Press of Florida. 492 pages, 70.00 USD, Cloth.



With the publication of Volume VII, a milestone has been reached in the monumental *Flora of Florida* project. The coverage of all dicot taxa is now complete. Only the much-anticipated monocot treatments remain outstanding, these to be completed in Volumes VIII through X.

The *Flora of Florida* project began in 2000 with the publication of Volume I (Pteridophytes and Gynmnosperms). Following a lengthy hiatus, a flurry of activity has brought the Flora to an advanced state. Reviews of Volumes II & III, IV, V, and VI can be read in *The Canadian Field-Naturalist* 130: 248–249 https://doi.org/10.22621/cfn.v130i3.1890, 131: 375 https://doi.org/10.22621/cfn.v131i4.2090, 132: 68 https://doi.org/10.22621/cfn.v132i1.2121, and 133: 70 https://doi.org/10.22621/cfn.v133i1.2343, respectively.The ambitious initial goal of completing the Flora in 2020 suddenly became untenable in a world reordered by the COVID-19 pandemic, but there is every reason to still expect it to be completed soon.

Volume VII describes taxa in families of major significance across North America, such as Orobanchaceae, Caprifoliaceae, and Apiaceae. The Asteraceae, however, constitute the most significant component, occupying the majority of the volume's pages. Of the approximately 800 species, subspecies, varieties, and named hybrids within the 12 families treated in the volume as a whole, some 600 taxa in 139 Asteraceae genera are presented here. The large diversity within Asteraceae genera familiar to northern botanists is startling; 21 *Solidago*, 29 *Symphyotrichum*, and 16 *Eupatorium* taxa, for example, are represented here. A listing (and explanation) for numerous excluded species that are unconfirmed or reported in error also appears at the conclusion of each generic treatment.

The comprehensive treatment of synonymy that has been a hallmark of *Flora of Florida* continues in Volume VII. Many taxa have a dozen or more synonyms listed but *Taraxacum officinale* L. tops the bill with 40 names. There would be 'only' 32 synonyms, however, had *Taraxacum erythrospermum* Andrzejowski not been combined within *T. officinale* in an unexplained contradiction of the *Flora of North America* treatment (the only taxonomic reference for the genus). The synonymy treatments in *Flora of Florida* will provide valuable information anywhere where the nomenclature of these taxa is under consideration.

Keys updated from Wunderlin's *Guide to the Vascular Plants of Florida* (University of Florida Press, 1998) are placed immediately after each genus description, with alphabetically arranged species treatments following. Individual treatments comprise concise and usually satisfactory physical descriptions, but with only 'bare bones' distributional and ecological information. Unfortunately, there are no illustrations—not even a county map of Florida. Readers are encouraged (and will need) to consult the on-

line *Atlas of Florida Plants* (http://florida.plantatlas.usf.edu) for photos and more detailed range information. This constraint reduces the effective comparison of distributional and ecological characteristics of Floridian populations with those beyond state boundaries. In that light, the English language interpretation/translation of Latin names is perhaps not the best use of limited text space. These are interesting, however. I enjoyed learning, for example, that the epithet for *Hasteola robertiorum* L.C. Anderson was selected because three botanists named Robert had studied that Florida endemic!

Although Florida is exceptionally rich in endemic and subtropical plants, a surprisingly large component of the local flora extends northward into the northeastern United States and adjacent Canada. The Canadian range of such taxa appears to be accurately reported for the most part. Canadian representation is also conspicuous in the mention of taxonomists who defined many of the taxa treated here, including Bernard Boivin, Kathleen Pryer, John Packer, and especially John Semple for his work with Asteraceae.

The physical structure of the book is somewhat contradictory. On the one hand the text font is clean, easy to read, and printed on high quality paper. The cloth cover is attractive and sturdy, as befits a reference work. On the other hand, the binding on Volume VII is of surprisingly poor quality. The weak paper (not cloth) connection between the cover side boards and the spine is already separating after only light use of the review copy, as it did with the review copies of Volumes V and VI before it. Unless this is just a feature of review copies and not representative of normal production quality, that represents an unfortunate production flaw that is all the harder to understand given the high cost of an otherwise uncomplicated book. If so, let us hope this is corrected for the final three volumes.

More small glitches were noted in the factual context of this volume than in previous volumes of the Flora. The statement (p. 46) that *Lobelia spicata* Lamarck is known "only from *the* north of Florida" [emphasis mine], for example, undoubtedly was intended to state, "only north of Florida". Small words, big difference. Rogers McVaugh is erroneously described (p. 39) as the authority for *Lobelia amoena* while other botanical literature and the *Atlas of Florida Plants* cite this as *L. amoena* Michaux (1802). Although *Helianthus microcephalus* Torrey & Gray is reported to occur in Ontario (p. 275), there is no valid record reported in Canadian literature. The authority and publication date for Calyceraceae (R. Brown ex L.C. Richards 1820) are absent (p. 55), as is an explanation (p. 166) of the origin for *Brickellia* Elliott (commemorating Irish-born physician and naturalist John Brickell, 1748–1809).

Some such small issues are inevitable in a work of this complexity, however, and few if any constitute significant issues affecting the worth of this volume. And Volume VII is worthy. Indeed, it represents a particularly important component of the *Flora of Florida*. With each new volume, the Flora becomes an increasingly valuable floristic tool that is applicable far beyond the boundaries of that state, extending meaningfully all the way up here to the Great White North.

DANIEL F. BRUNTON
Ottawa, ON, Canada

ORNITHOLOGY

Birds in Winter: Surviving the Most Challenging Season

Roger F. Pasquier. Illustrated by Margaret La Farge. 2019. Princeton University Press. 304 pages, 29.95 USD, Cloth or E-book.

Full disclosure: I like books that deal with a broad topic in Ornithology, and I especially like ones that treat that topic from a natural history perspective, so I began with a positive bias towards this book. From the title, and also from the cover picture, showing a crossbill perched on a snowy branch, I anticipated that it would be mostly about how birds cope with tough physical conditions in winter at high latitudes. That material is here, but there is much, much more. This is a very wide-ranging volume.

The book begins by describing migration as a strategy for avoiding cold weather and short days and continues with a discussion of food caching for winter survival, the ecology of migrants in their wintering areas, and the maintenance of territories and winter flocking behaviour among wintering birds, both resident and migrant; strategies to cope with cold weather and short days do not get much attention until 120 pages in. Following two chapters on the rigours of high latitude winters (Survival, The Winter's Day) the author moves to preparations for spring and departure from the wintering grounds. The book concludes with a chapter on conservation and a chapter on climate change and its observed and predicted impacts.

The many topics covered are reflected in the author's recourse to a very large number of references: more than 600 are cited, of which about half are dated after 2000, so this is a pretty up-to-date account. There is a very judicious combination of broad generalizations and specific examples. For instance, we are told, "For many birds, direct competition [in winter] is reduced or avoided when each sex and age group differs in habitat choice, feeding specialty, anatomy or winter range" (p. 63). This generalization is then exemplified by three Scandinavian owls that have contrasting migration strategies. It is inevitable that some generalizations provoke counterexamples in the mind of the reviewer, but I found few that I disagreed with entirely and many that I found useful and thought-provoking. This book would be an excellent source of ideas around which to develop hypotheses and tests for any graduate student thinking about doing a project relating to migrant birds.

Unfortunately, an inevitable result of covering so many topics is that the text is very dense with facts and this does make reading hard going in some places. This is not really a book to read straight through, but rather one to dip into for particular topics. Another small reservation I had about the book concerns the illustrations, by Margaret La Farge. They are well designed to complement the text, but some combination of paper and printing seems to have reduced the clarity for some of them. It is worth noting that the publisher's claim: "*Birds in Winter* is the first book devoted to the ecology and behavior of birds during this most challenging season", is not strictly true, as a book by Jennifer VanVoorst with the same title was published in 2016 (Bullfrog Books). However, that is a children's book, designed as a teaching aid.

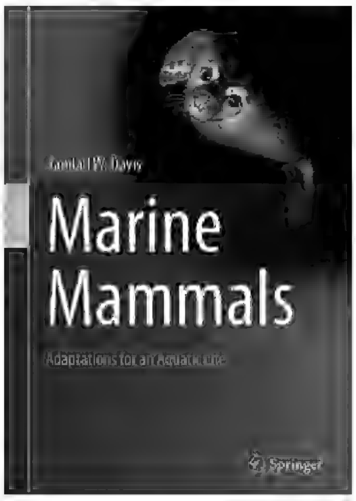
I thought I knew plenty about winter challenges for birds, but the book made me appreciate the huge ramifications winter has for the feathered tribe. Even birds that never leave the tropics feel the competition from migrants that spend more than half the year in their habitats. Surprisingly, considering the importance of the subject, the statement that this is the first general review of wintering in birds does appear to be true for adult natural history books, so this is a really welcome publication on a previously neglected topic. I found it a tremendous compilation of ideas and facts about wintering birds and I think it deserves to be very widely read.

TONY GASTON
Ottawa, ON, Canada

ZOOLOGY

Marine Mammals: Adaptations for an Aquatic Life

By Randall W. Davis. 2019. Springer International Publishing. 192 pages, 99.99 USD, Cloth.



Marine Mammals is a scientific text that reviews the different adaptations of marine mammals that allows them to survive in a marine environment. This book comes from the perspective of physiology, and thus it focusses primarily on the different physiological and sensory adaptations specific to marine mammals. There are a few different ways to categorize marine mammals, and this book specifically includes all members of Cetacea (mysticete and odontocete whales), Sirenia (dugongs and manatees), Pinnipedia (seals and sea lions), and Sea Otters, and excludes other peripheral marine mammals such as Polar Bears and aquatic sloths. This comparative physiological approach offers a powerful perspective on convergent evolution—how mammals on different evolutionary trajectories all became adapted to living in the same harsh environment that is so different from the terrestrial environment that their ancestors lived in.

The eight general topics covered in this text are: 1) evolution; 2) respiration and the effects of pressure; 3) metabolism and thermoregulation; 4) locomotion; 5) physiological adaptations for breath-hold diving; 6) sensory systems; 7) feeding and digestion; and 8) sleep. As an ecologist, I would have liked to see information on behavioural adaptations; however, the text is already more than 300 pages long and is full of detailed information, so there was clearly no room for more topics beyond physiology. This book would be excellent reference material for anyone studying marine mammals (both students and researchers), and is also filled with information that would be interesting for any naturalist who wants to dive deep into what makes marine mammals so different from their terrestrial counterparts. Some knowledge of physiology and anatomy will be required to understand some of the material in this book.

One of my favourite aspects of this book is how it frames the entire story around the evolutionary history of marine mammals. Chapter 2 gives an interesting overview of how marine mammals evolved from their terrestrial ancestors, looking at transitions from life on land to life in the water. This sets the stage very nicely for all of the different physiological adaptations that mammals needed to acquire to be able to live in the water. A very useful feature of this book, especially for those wishing to use it as reference material, is that each chapter ends with a good summary, which the reader can quickly skim to determine if the information that they are looking for is present.

As an ecologist who studies bioacoustics (the sounds made by animals) in marine mammals, I was particularly interested in Chapter 7 (Sensory Systems), which includes a section on audition and sound production (section 7.2.1). The section is very detailed, and even describes separate adaptations of the four different groups of marine mammals that this book focusses on. Based on my own understanding of hearing and vocalizations made by cetaceans and pinnipeds, this section does a good job of reviewing the many aspects of hearing and audition in these marine mammals.

The author, Randall Davis, is a professor at Texas A&M University who studies the behaviour and diving physiology of marine mammals. According to the Preface for this book, he wrote a review article on adaptations for diving physiology (Davis 2014), and the editor asked him if he would be willing to turn his review article into an entire book on adaptations for aquatic life. Davis then spent the next five years diving into the scientific literature to determine what adaptations marine mammals have evolved for the life aquatic. This book is the culmination of a tremendous amount of time digging into the scientific literature, and I think that the author has done an excellent job of presenting and summarizing all of this information.

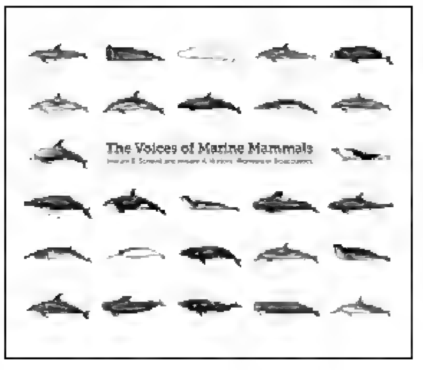
Literature Cited

Davis, R.W. 2014. A review of the multi-level adaptations for maximizing aerobic dive duration in marine mammals: from biochemistry to behavior. Journal of Comparative Physiology B 184: 23–53. https://doi.org/10.1007/s00360-013-0782-z

WILLIAM D. HALLIDAY
Wildlife Conservation Society Canada,
Whitehorse, YT, Canada and
School of Earth and Ocean Sciences, University
of Victoria, Victoria, BC, Canada

The Voices of Marine Mammals: William E. Schevill and William A. Watkins: Pioneers in Bioacoustics

Edited by Christina Connett Brophy. 2019. New Bedford Whaling Museum. 125 pages and flexi-disc insert of audio recordings, 29.99 USD, Paper.



The field of marine bioacoustics, or the study of sounds made by marine life, really only began after World War II. Navies round the world began developing underwater acoustic technology during the war to detect enemy submarines and, following the war, biologists began using and further developing this technology to study marine life. Two researchers from Woods Hole Oceanographic Institution (WHOI) were truly pioneers on this front: William (Bill) Schevill and William (Bill) Watkins. *The Voices of Marine Mammals* provides a really interesting overview of the many ways that Schevill and Watkins contributed to marine bioacoustics and marine mammal biology. Most chapters were written by authors who were touched by Watkins and Schevill in some way, whether they were trained, supervised, or mentored by Watkins and Schevill or collaborated with them.

The impetus behind this book was the donation by WHOI of the entire collection of whale and seal audio recordings made by Watkins and Schevill to the New Bedford Whaling Museum (NBWM). The NBWM then undertook the project of archiving, cataloguing, and digitizing this immense collection of whale and seal vocalizations. To celebrate this collection and the careers of Schevill and Watkins, the NBWM put together this book and released the Watkins Marine Mammal Sound Database (https://cis.whoi.edu/science/B/whalesounds/index.cfm). People interested in learning more about the history of marine bioacoustics should read this book and should also visit the Watkins database website to listen to the marine mammal sounds discussed within the book. The hardcopy of this book also comes with a flexi-disc containing excerpts from a recording made by Watkins and Schevill in 1962, entitled "Whale and porpoise voices: a phonograph record". These excerpts include five tracks from the 19 on the original record. The full, original record and its introductory 26-page booklet can be downloaded from https://hdl.handle.net/1912/7431. This flexi-disc is a nice addition to the book for anyone with the equipment to play it.

This book presents a great combination of biography and history of biology. It is full of interesting anecdotes about the lives of Watkins and Schevill, their adventures in the field, how they started different research projects and collaborations, and how they affected the careers of many researchers who are themselves at the top of their fields today. It also provides many examples of how Watkins and Schevill advanced different aspects of marine mammal science: nine of the 11 chapters in *The Voices of Marine Mammals* are dedicated to specific frontiers in marine mammal science that these scientists helped to advance. While most of their influence was related to marine mammal bioacoustics, they were also involved in developing the earliest tracking tags that could be attached to whales, which is a type of technology that is crucial to much of what we know about the movements of whales.

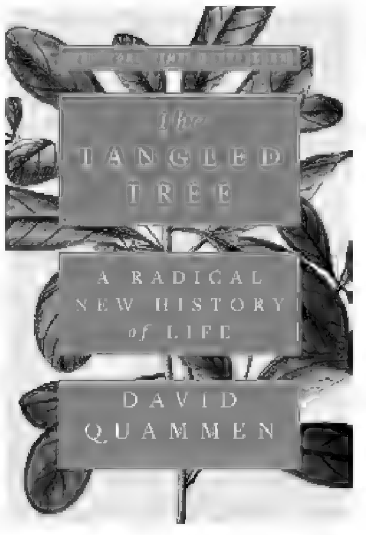
The Voices of Marine Mammals is well-written and should be easy to understand for readers with a basic knowledge of biology and science. It should be especially interesting to those interested in marine mammal science and the history of biology.

WILLIAM D. HALLIDAY
Wildlife Conservation Society Canada, Whitehorse, YT, Canada and
School of Earth and Ocean Sciences, University of Victoria, Victoria, BC, Canada

OTHER

The Tangled Tree: A Radical New History of Life

By David Quammen. 2018. Simon and Schuster. 480 pages, 25.00 CAD, Paper.



The Tangled Tree is a meticulously researched work, mainly a popular science text written for the public but also part memoir, not of Quammen, but of the history of the Tree of Life itself, those scientists who brought it into being, and those who rattled it. This was my first foray into Quammen's extensive body of work, so I cannot compare this book to his other titles, but this is a book that takes its time. Re-reading the introductory material after finishing the book I can see the connections that he makes, but a first read does not offer much of a road map for the book's structure, and the rest of the work proceeds in the same unhurried way.

A hefty 480 pages and 84 chapters, *The Tangled Tree* is broken into seven main parts in addition to a short introduction, acknowledgements, extensive notes, and a detailed bibliography. Quammen lays the groundwork in Part I, Darwin's Little Sketch, providing biographies of key figures in the history of our emerging understanding of evolution. Each chapter within a section is quite short, only a few pages long, and there is some truly personable writing here. In large part, this book is a biography of key figures in the step-by-step discovery of the Tree of Life, beginning with microbial taxonomy, moving along with the discovery and acceptance of Archaea and endosymbiosis, and, eventually, horizontal gene transfer. Featured are a physical description of each researcher, their academic history, personality, relationships with others in the field, quarrels and challenges, triumphs and rejected papers. Quammen jumps around in time somewhat, and not all the characters are savoury—the criminal allegations against them are also dutifully listed. It also explores the methods of these key discoveries, describing the experimental techniques, equipment, and all the radiation and explosive compounds that they necessitated.

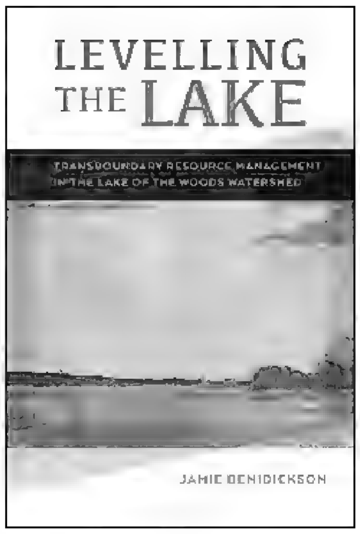
For me, the book really picks up steam after Chapter 51 when horizontal gene transfer jumps into the fray. From antibiotic resistance that hops from chickens to farm workers, to new questions about the history and future of life on earth, the last third of *The Tangled Tree* rewarded my persistence. Although I found that the biographical focus made for a ponderous read at times, there is never any sense that the author is uninterested in the subject matter, and those moments where Quammen writes his own thoughts, although rarer, are quite creative and playful. For example, on the topic of over-prescribing antibiotics in the case of viral infections, against which they are useless, Quammen states: "you might just as well try to hose the dirt off of your driveway using a flashlight" (p. 232). I will absolutely be borrowing this—with attribution, of course.

A central figure throughout the book is Carl Woese, who pioneered the technique of using 16S RNA to characterize and compare microbes. The last three chapters are almost entirely dedicated to Woese's declining health, and his death ends the story at Chapter 84. This is an appropriate ending to the style of book Quammen has written. If you are a fan of biography and enjoy peeking into the sometimes petty, churlish, and fraught side of scientific discovery as well as its highlight reel, you will likely enjoy the structure of this book. If you have come for the 'new stuff', such as endosymbiosis and horizontal gene transfer, be aware that you will have some wading to do. This is not to say that *The Tangled Tree* doesn't teach you fascinating new things; as you would expect from the title, there is much discussion of the Tree of Life—from Darwin's small preliminary sketch scrawled in his "B notebook" to the discovery of the Archaea, and the long standing and impassioned debates around the Tree's utility as an organizing conceptual model. Quammen has collected stories and anecdotes from sources such as archived correspondences, published articles, biographies, and a multitude of in-person interviews to create a very personal history of the field of microbiology as it relates to the eventual discovery of horizontal gene transfer, but it does take its time in getting there. There are real nuggets of excellent writing and genuine interest here, but I suspect the style will not be for everyone.

HEATHER CRAY
Halifax, NS, Canada

Levelling the Lake: Transboundary Resource Management in the Lake of the Woods Watershed

By Jamie Benidickson. 2019. University of British Columbia Press. 367 pages, 89.95 CAD, Cloth.



The Lake of the Woods watershed straddles the borders of Ontario, Manitoba, and Minnesota in the heart of the continent, providing a complex regional context for the examination of resource management issues of wider relevance. The watershed encompasses roughly 70 000 km^2, extending over 400 km from its outlet at the Winnipeg River near Kenora, Ontario, east to beyond Quetico Provincial Park and the Boundary Waters Canoe Area Wilderness. The broad geographic scope tackled by *Levelling the Lake* is matched by an ambitious time frame covering the last century and a half of resource management. Joining 30+ other titles in UBC Press' Nature/History/Society series, including his 2007 *The Culture of Flushing: A Social and Legal History of Sewage,* Jamie Benidickson's latest work explores the environmental, legal, and regulatory history of this vast area.

Although we pay little thought to the provincial boundaries today, as Benidickson chronicles, jurisdiction in this area was hotly disputed between the governments of Ontario and Canada in the latter part of the 19th century. This had profound effects on how natural resource extraction and development proceeded over the decades to come, and how the obligations of Treaty 3 were met (or not). For example, owing to the federal-provincial dispute, the delineation of reserves was not finalized until over four decades after the signing of Treaty 3 in 1873, during which time Indigenous communities lost prime agricultural lands they formerly used for their gardens. Indeed, an underlying current of broken treaty promises runs throughout the book and has one seriously questioning the "honour of the Sovereign" (p. 56).

Fourteen chapters examine how the various levels of government (e.g., federal, provincial, state, municipal) wrestled with often competing interests of hydroelectric development, forestry, mining, fishing, tourism, and recreation, as well as municipal development and agriculture. Although it makes for a complex story, *Levelling the Lake* benefits from its broad scope because so many component parts are intertwined, if only by their impacts on water quality and quantity. For example, the early timber industry in the watershed was particularly dependent on the hydropower required for its mills, and the control of flows and water levels facilitated log driving.

The strength of *Levelling the Lake* is its scholarship. Professor Benidickson teaches environmental law at the University of Ottawa, where he is a highly respected member of the Centre for Environmental Law and Global Sustainability. Not surprisingly, *Levelling the Lake* is impressively researched, and provides 66 pages of endnotes, as well as suggested readings and an index. The maps are effective despite the lack of colour, and essential for orienting the reader. I found the 19 historical photos a treat, particularly for familiar locales, and wished there had been more. The inclusion of graphic timelines or additional charts might have helped readers hang on to the narrative thread when at times it is difficult to navigate the maze of names and dates. Fortunately, Benidickson (largely) manages to render complicated subject matter comprehensible, typically with a deft or wry turn of phrase. For example, when discussing the impossibility of securing both uniform level and uniform outflow on Lake of the Woods, the author remarks, "Anyone likely to confuse management of a large watershed with filling a bathtub was thus on notice to expect disappointment" (p. 11).

Levelling the Lake reminds us that history is very much alive and provides some cautionary tales. The Lake of the Woods Rainy River sturgeon (*Acipenser fulvescens*) populations that crashed a century ago from overfishing and habitat degradation have still not recovered. Historical mercury contamination in the English-Wabigoon River system from a pulp mill near Dryden continues to have devastating impacts on downstream Indigenous communities. The enormous pit at the former Steep Rock Iron Mine near Atikokan continues to fill with water and without mitigation will eventually overflow, risking potential downstream effects (in 1951, turbidity from the site reached as far as Fort Frances!). Yet, Benidickson also provides some positive examples of mechanisms enabling a more sustainable approach to water management, such as the International Joint Commission (IJC) and the world-renowned Experimental Lakes Area (ELA) research program.

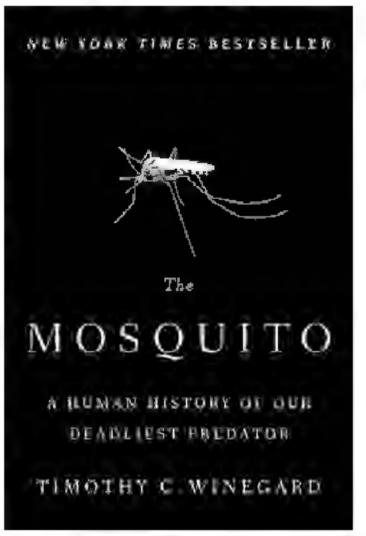
Levelling the Lake provided a new lens through which to view my backyard, from lesser-known events like the misguided expulsion of the Sturgeon Lake Indian Band from Quetico Provincial Park to

broader themes of our role in resource stewardship. This book will similarly appeal to anyone with a strong interest in environmental history, particularly students and scholars of the social sciences, humanities, and Indigenous studies, not to mention resource managers in this neck of the woods and beyond.

ROBERT F. FOSTER
Northern Bioscience, Thunder Bay, ON, Canada

The Mosquito: A Human History of Our Deadliest Predator

By Timothy C. Winegard. 2019. Dutton imprint, Penguin Random House. 496 pages, 28.00 USD, Cloth.



For most people in North America any reference to mosquito means the dreaded hum which, if not eradicated with a quick slap, will translate into an itchy, red, annoying bump. So, should we believe Timothy Winegard's assertion in the title of his latest book that mosquitos truly are "Our Deadliest Predator"? The first chapter of the book does dispel any skepticism with a quick rundown of animals most lethal to humans and mosquitos clearly dominate the top of the list, causing over two million deaths per year; the next "animal" perhaps surprisingly is ourselves, with humans causing 475 000 deaths per year. The numbers then drop off quickly to include animals such as snakes at 50 000, dogs 25 000, crocodiles 1000, and the much-feared shark at only about 10 deaths per year.

The mosquito is, of course, only the disease vector, the real cause of death being one (or more) of the 15 virus, worm, or protozoan pathogens delivered by its bite. Yellow fever is the most lethal of the viruses carried by mosquitos, that also include less virulent dengue, chikungunya, Mayaro, West Nile, Zika, and variants of encephalitis. Elephantiasis, debilitating and disfiguring but not lethal, is caused by a filarial worm. Malaria, which currently is responsible for the greatest number of deaths each year, is a protozoan.

So while Winegard's book quickly captured my interest by asserting the lethal capacity of mosquitos, it just as quickly lost my interest by embarking on a history of the world shaped not by human ambition and determination but by Winegard's assertions regarding the deadly influence of mosquitos. This would have been fine had the book made convincing arguments. In other words, for a natural history book to be enjoyable it must be plausible and supported by good evidence.

As a scientist reading Winegard's book, my inclination was to scrutinize what was being said and fact check the inferences being made. As the pages turned and my skepticism grew my reading enjoyment declined, making it harder and harder to pick the book up to embark on another chapter. For example, this sweeping statement is made on page 38: "the symbolism associated with chrysanthemums in global culture has been directly prejudiced by the mosquito". Has it really? Can you make this statement when the flower is associated with death in countries with high historical rates of mosquito borne disease, while in other countries the flower symbolizes love, joy, and vitality? Almost as an aside the book also loosely links chrysanthemums, death, and global culture to the fact chrysanthemums are related to plants which produce pyrethrin, long recognized for its insecticidal properties. So, while it is true chrysanthemums signify different things in different cultures, there are no data to suggest that this is in any way linked to mosquito borne disease.

Had there been relatively few such stretches of the imagination I might have tolerated Winegard's musings, but my enjoyment of the book became overshadowed by an annoyance at far too many unsubstantiated conclusions of how mosquitos influenced human history. Following the reference to chrysanthemums, Winegard states, "Cloves, nutmeg, cinnamon, basil, and onions all soften malaria's symptoms [do they?], which may explain why, for millennia, people have added these notionally hollow flavorings to their diets" (p. 38). Could one not also conclude that the human palate simply enjoyed these flavours or that their medicinal uses are completely unrelated to mosquitos? On page 42 Winegard attributes the all-consuming global coffee culture and the fortunes of the likes of Starbucks to the stimulating properties of coffee which, he infers, may have been used medicinally against mosquitos based, presumably, on the fact that coffee originated in Ethiopia, a country with mosquito borne diseases.

Speculation escalates to a much larger scale as Winegard reviews the rise and fall of human empires, beginning with the dominance of Bantu tribes in Africa because they carry the recessive gene for sickle cell which is known to provide some protection from malaria. Many Africans continue to pass on this recessive trait, but millions of Africans also

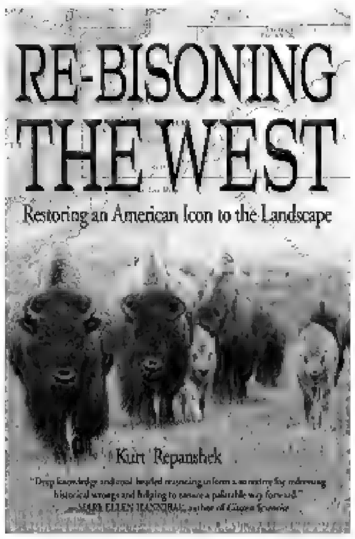
still die from malaria. The fall of the Roman empire is attributed to a mosquito infested swamp, without exploring more thoughtful analyses, such as Thomas Homer-Dixon's in his book *The Upside of Down: Catastrophe, Creativity and the Renewal of Civilization* (Knopf Canada, 2006), which explains the fall in more complex terms of population growth, resource supply and demand, and governance. I could go on to include the continental conquering aspirations of Genghis Khan and his grandson Kublai Khan, both thwarted by mosquitos in their various campaigns to expand the Mongol empire in Europe and Southeast Asia, or the initiation of the slave trade and later its abolition, or simply why humans build homes on hilltops.

There is no doubt that mosquito-borne diseases are deadly—they are estimated to have reduced humanity by half over the millennia. And by highlighting the legacy of mosquito-borne disease, Winegard's book contributes to other recent books that consider the interplay between humans' global pursuits and the spread of disease, such as the work of Jared Diamond in *Guns, Germs, and Steel* (Norton, 1999) and Charles C. Mann in *1491: New Revelations of the Americas Before Columbus* (Knopf, 2005). Given the current COVID-19 pandemic, reading a history book with a focus on disease does make you re-evaluate the potential influence of less obvious, hidden, and simply unknown factors that underpin history. Thus Winegard's book is timely. In 2020 humans instigated a novel, rapid, and widespread disease outbreak that is changing human history in ways that we can not yet know, from small things like learning how to make your own bread to big things like the rise of the home office with all the social, environmental, and economic impacts of this.

Brent Tegler
Liana Environmental Consulting
Fergus, ON, Canada

Re-Bisoning the West: Restoring an American Icon to the Landscape

By Kurt Repanshek. 2019. Torrey House Press. 248 pages, 25.50 CAN, 18.95 USD, Paperback.



I have always had an interest in American Bison (*Bison bison*) and feature them prominently in two of my books, *My Yellowstone Experience* (Eastern Coyote Research/White Cottage Publishing, 2013) and *The Trip of a Lifetime* (www.easterncoyoteresearch.com, forthcoming), so it was refreshing to find a person who shares my fascination with these pre-historic looking, shaggy-furred, woolly creatures. Bison have had more influence on man than all other Plains animals combined (p. 34), providing food, shelter, and warmth for many human cultures (pp. 9, 31). In this book, author Kurt Repanshek captures the past, present, and future of bison in North America. The author was well versed to tell this story because he is a former Associated Press reporter and is currently editor-in-chief of National Parks Traveler, the only editorially independent media organization that covers national parks and protected areas on a daily basis. This scholarly work weaves personal experiences of him visiting areas where bison currently live, along with combining science and history, into a very readable and detailed product containing 18 pages of endnotes and a nine-page bibliography.

Bison populations approached an estimated 60 million individuals historically (p. 56). While a great map on the introductory pages shows bison originally living across the country all the way to the eastern states, and from Canada to Mexico, it clearly is a species most closely associated with the Great Plains, a topographic tabletop that is 500 miles (805 km) east to west and 2000 miles (3200 km) north to south (p. 17). In the chapter The Great Slaughter we learn how the buffalo, as bison are often called in North America, population dipped down to ~100 wild bison before those were captured and brought into captivity (p. 153). Repanshek then explained in deep detail how just a half dozen forward thinking visionaries, including Teddy Roosevelt, saved the species from a “veritable tragedy of the animal world” (p. 91). They were kept in six herds, including one in New Hampshire (p. 147), and bred (p. 154). Because those bison came from diverse bloodlines and herds (p. 148), the species has a surprising amount of genetic diversity to this day (p. 129). In addition to these herds, a small population of about two dozen survived in Yellowstone National Park (pp. 71, 134). It is difficult to imagine seeing herds of bison so massive that they stopped river traffic when crossing streams, and even derailed trains that tried to roll through a herd on the Plains (p. 58). It is even more remarkable and difficult to comprehend that in just a couple of decades they were nearly exterminated (pp. 62–71) and had to be taken out of the wild to be saved. In the 1870s, people were shooting them from trains for fun, and toward the end of the Great Slaughter in the 1880s, they were getting killed in such astounding numbers that only their coats (pp. 70–71), or even their tongues (a delicacy; p. 62) were kept, with the body left to rot. The colossal ignorance and greed by European Americans almost resulted in their disappearance.

The lives of Native Americans and bison were intertwined, with different tribes having various names for North America’s largest mammal. Many origin stories for Plains peoples have to do with buffalo and natural features, such as the opening to the cave system at Wind Cave National Park (pp. 34–35). Because native peoples viewed bison with honour and dignity (p. 35), the period between 1846 and 1890 was a cultural catastrophe when bison were slaughtered to near extinction (p. 37). As white settlements grew, nomadic peoples were doomed with the conquerors dictating to the conquered where and how to live (pp. 38, 61). That economic blow continues today, more than a century after the Great Slaughter (p. 39), with many of those tribes still living in poverty.

Unfortunately, the racism (p. 60) and prejudice (p. 138) that fueled the bison’s downfall is alive and well and has slowed bison recovery. Montana’s position of not allowing bison to be quarantined or roam outside of Yellowstone National Park is perhaps the most blockheaded and illogical of all (p. 43). I have previously documented the hypocritical stance of rural states blocking level-headed strategies for allowing bison more room to roam on federal land that all taxpayers pay for (Way 2013), so I was glad that the author covered this at length, repeatedly touching on the political, prejudiced actions taken against Native Americans. Agencies use diseases such as brucellosis as a scapegoat for not wanting bison to be treated as wildlife yet leave other species, most notably Elk, alone even though they have a higher frequency of the disease (p. 50). This has led to modern day slaughters of upward of 1000 bison during particular harsh winters. Repanshek eloquently describes how the boundaries of parks don’t take into consideration the migratory nature of wildlife like bison (p. 120), which hamstrings the National Park Service to local politics

and political boundaries. Fortunately, the pressure is increasing on Montana to compromise for the good of the bison (p. 52).

There are currently about a half million bison residing in North America with these animals divided into commercial and conservation herds (pp. 13, 129). Most commercial herds are raised more or less like livestock for meat and hides, although some can live relatively similar to animals in more wild settings. For example, Ted Turner owns 51 000 head of bison on his combined properties (p. 13) and a few of them are larger than some of the US's national parks that contain bison. The second half of *Re-Bisoning the West* focusses on modern-day conservation herds and the potential to establish bison in additional areas. These are the bison living in national parks like Yellowstone, Badlands, Wind Cave, and Grand Teton, as well as in state parks, land preserves, national wildlife refuges, and, increasingly, on Native American reservations. However, without room to roam, conservation herds are limited and are often capped at a certain number based on how many animals the land can support (p. 14). Only about 4%, or 20 000 bison, exist as conservation herds living at least a semi-wild existence within those reserves. The author makes convincing arguments to restore the wild, ecological function of bison on additional landscapes as it is a keystone animal influencing the survival of other species (pp.15–16). Critical to that is to increase existing herds and establish populations in new areas (p. 199), with the goal of increasing bison numbers to over one million (p. 13). We owe it to bison as they "deserve the opportunity to regain a more solid footing, to leave some wallows on the open plains" (p. 200).

The book concludes with a couple of encouraging chapters detailing how some states like Utah and Indian reservations, such as the Wind River, Fort Peck, Blackfeet, are establishing conservation herds on their lands (pp. 156, 164, 178). Repanshek also describes how current federal lands, like national grasslands, can house bison. Some surround national parks (e.g., Buffalo Gap enveloping Badlands) and could be used to expand the area that bison are able to roam. The managers of American Prairie Reserve in eastern Montana have a vision of linking protected land to create a 3.5 million-acre (1 416 400 ha) reserve that might accommodate up to 10 000 bison. These bison are in addition to the 19 herds managed on Interior Department lands by the National Park Service, U.S. Bureau of Land Management, and United States Fish and Wildlife Service (p. 156). The author states that bison populations need to be large (ideally over 1000; p. 159) and connected to maintain genetic diversity and ecological functioning. To succeed, bison need to be given room to roam and not be treated like livestock (pp. 167–168, 195) as they are the key missing element of the Plains ecosystem (p. 171). Repanshek argues that because bison are the US's national mammal, they should be given more respect with a paradigm shift away from viewing them as livestock (p. 195). To be specific, the author details 13 additional locations where bison could live, including Great Sand Dunes National Park and Agate Fossil Beds (p. 173), and notes that Wyoming, the Dakotas, Nebraska, Colorado, Kansas, and Oklahoma have vast spaces held in public domain that could have bison (p. 175).

I really enjoyed this book and highly recommend it for anyone interested in wildlife conservation, wildlife restoration, the western United States, environmental justice, and the US's national parks. It is well written yet contains repetitive information at times, such as discussing population numbers from certain places (e.g., pp. 71, 134, 167, 189) and historic events like Yellowstone's enabling legislation (pp. 71, 130). But these did not necessarily distract from the read because when the author discussed the history of bison in the first half of the book, he also detailed recovery efforts now happening in many of those locations. He eventually circled back to those locales in more detail, which made the book more engaging even if containing a non-linear flow. My only legitimate complaint was that there was no index. I took 1.5 pages of notes and still at times had to search through highlighted passages to find information, such as specific places, which was often challenging because of information that was repeated in multiple sections.

Literature Cited

Way, J.G. 2013. [Book Review] In the Presence of Buffalo: Working to Stop the Yellowstone Slaughter. Canadian Field-Naturalist 127: 366–367. https://doi.org/10.22621/cfn.v127i4.1498

JONATHAN (JON) WAY
Eastern Coyote/Coywolf Research, Osterville, MA, USA

BOOKS IN BRIEF

As an occasional addition to our Book Review section, Books in Brief will offer quick descriptions of books received and available (†) for regular, full reviews.

†**International Wildlife Management: Conservation Challenges in a Changing World.** Edited by John L. Koprowski and Paul R. Krausman. 2019. Johns Hopkins University Press. 248 pages, 74.95 USD, Cloth or E-book.

†**The North American Model of Wildlife Conservation**. Edited by Shane P. Mahoney and Valerius Geist. 2019. Johns Hopkins University Press. 184 pages, 74.95 USD, Cloth or E-Book.

†**Quantitative Analyses in Wildlife Science**. Edited by Leonard A. Brennan, Andrew N. Tri, and Bruce G. Marcot. 2019. Johns Hopkins University Press. 344 pages, 74.95 USD, Cloth or E-book.

†**Renewable Energy and Wildlife Conservation**. Edited by Christopher E. Moorman, Steven M. Grodsky, and Susan P. Rupp. 2019. Johns Hopkins University Press. 280 pages, 74.95 USD, Cloth or E-book.

Each of these volumes was published late in 2019 by Johns Hopkins University Press (JHUP) in partnership with The Wildlife Society (TWS), a relationship that dates back to at least 2013. JHUP's origins date back to 1878 while TWS, now an international non-profit, was formed in 1937. A major partner of the TWS is the United States (US) Department of the Interior's Bureau of Land Management, founded in 1946, with a Wildlife Division opening in 1965 after almost a decade of hiring wildlife biologists (https://wildlife.org/blm/). Thus, the roots of these partnering organizations are very deep, a fact reflected in the extensive publication and other programs of TWS. *The Journal of Wildlife Management* (since 1937), *Wildlife Monographs* (since 1958), and the online-only *Wildlife Society Bulletin* are peer-reviewed, while *The Wildlife Professional* is a members' magazine. In addition, TWS launched the Conservation Affairs Network—with its own newsletter—in 2014 and has membership in 11 major coalitions comprised of many organizations engaged in wildlife issues. If all this is not enough, 27 Working Groups are available to TWS members involved in many aspects of wildlife conservation and management in the US and elsewhere.

Essentially, the history of the TWS mirrors the history of the development of wildlife conservation and management as both intellectual disciplines and policy practices. The contributors to these volumes reflect this background and, while many live and work in the US, people in other countries have provided chapters, especially in the volume on international wildlife management. Two Canadians are co-editors of *The North American Model of Wildlife Conservation*: Valerius Geist, a Professor, now emeritus, of Environmental Sciences at the University of Calgary since 1977, and Shane Mahoney, president and CEO of Conservation Visions Inc., based in Newfoundland, and director of the High Lonesome Institute in Colorado. In 2001, at a session of the 66th North American Wildlife and Natural Resources Conference, they (along with John F. Organ, then of the US Fish and Wildlife Service) presented a paper in which they "define[d] the key components of the model and discuss the role hunters and hunting had in constructing these components" (Geist *et al.* 2001: 176). Not surprisingly, hunting remains a subject for analysis and these three authors are involved in seven of the 13 articles in this volume.

The four volumes are all in the Wildlife Management and Conservation series, with Paul R. Krausman as senior editor, although no further information on the series is offered. Formats are similar and briskly efficient, with front matter kept to a minimum; all have Contents and Contributors, several add Acknowledgements, a Foreword and/or a Preface. The books then launch immediately into their 11–17 articles. Two of the volumes, *The North American Model of Wildlife Conservation* and *International Wildlife Management*, present their articles one after the other; in *Renewable Energy and Wildlife Conservation* and *Quantitative Analyses in Wildlife Science* they are organized in themed sections. Article presentation styles vary, but generally have internal divisions, sometimes a short abstract (*The North American Model of Wildlife Conservation*), usually an introduction, conclusion—or summary or discussion—followed by Literature Cited sections or Notes, in the case of *The North American Model*. Either way, these extensive citations could almost be called select bibliographies. Volumes are indexed and prices listed above are for non-members; TWS members receive price discounts of about 30%.

Too many topics are covered to mention here, but they reflect the concerns, thinking, and experience, of their authors, all of whom are experts in their topics, a generalization based on the wide range of universities, various levels of government, and conservation and other organizations to which contributors belong. The stated purposes and goals of each volume provide indications of their contents:

> We wanted to compile a volume that addressed the major challenges that we share in wildlife conservation around the world, written by a diverse group of international scien-

tists with similar aspirations. Furthermore, we wanted to provide advice on how to get involved in international wildlife management early in a career. (*International Wildlife Management*, Preface)

Its purpose is to present readers with the widest and most detailed coverage to date of the North American Model. The book's broader purpose, however, is to elicit thoughtful debate, not only about the Model … but also about wildlife's future in Canada and the United States. (*The North American Model of Wildlife Conservation*, Introduction, p. 7)

Our goal was to produce a volume that can give graduate students and other wildlife researchers an entree into some of the more widely used approaches to data analysis today … At the outset, we encouraged chapter authors to inject philosophical perspectives along with their technical expertise and guidance. (*Quantitative Analyses in Wildlife Science*, Preface)

Our goal … was to synthesize the extensive and rapidly growing base of scientific literature on renewable energy and wildlife into a single, comprehensive resource for wildlife ecologists, university students, policy makers, industry representatives, and environmental nongovernmental organizations. (*Renewable Energy and Wildlife Conservation*, Introduction, p. 8)

My brief overview of these books suggests that they present the science in balanced ways: raising questions, discussing issues without polemics, and attempting to reconcile, or at least address, the myriad complexities inherent in these fields. Although these books are aimed at professionals, interested laypersons would find much to digest in many of the articles.

Literature Cited

V. Geist, S.P. Mahoney, and J.F. Organ. 2001. Why hunting has defined the North American model of wildlife conservation. Transactions of the 66th North American Wildlife and Natural Resources Conference. Accessed 26 May 2020. https://www.conservationvisions.com/sites/default/files/why_hunting_has_defined_the_north_american_model_of_wildlife_conservation.pdf.

BARRY COTTAM
CFN Book Review Editor

NEW TITLES

Prepared by Barry Cottam

Please note: Only books marked † or * have been received from publishers. All other titles are listed as books of potential interest to subscribers. Please send notice of new books—or copies for review—to the Book Review Editor.

†Available for review *Assigned

Currency Codes: CAD Canadian Dollars, AUD Australian Dollars, USD United States Dollars, EUR Euros, GBP British Pounds.

BIOLOGY

Biology in Transition: The Life and Lectures of Arthur Milnes Marshall. Curated and Annotated by Martin Luck. 2020. Pelagic Publishing. 400 pages, 94.64 CAD, Cloth.

The Biology of Agroecosystems. Biology of Habitats Series. By Nicola Randall and Barbara Smith. 2020. Oxford University Press. 208 pages, 95.00 CAD, Cloth, 45.95 CAD, Paper. Also available as an E-book.

In the Hearts of the Beasts: How American Behavioral Scientists Rediscovered the Emotions of Animals. By Anne C. Rose. 2020. Oxford University Press. 240 pages, 55.00 CAD, Cloth. Also available as an E-book.

The Next Great Migration: The Beauty and Terror of Life on the Move. By Sonia Shah. 2020. Bloomsbury Publishing. 400 pages, 28.00 USD, Cloth, 19.60 USD, E-book.

Urban Deer Havens. By Clark E. Adams and Cassandra LaFleur Villarreal. 2020. CRC Press. 164 pages, 47.96 USD, Paper.

Urban Evolutionary Biology. By Marta Szulkin, Jason Munshi-South, and Anne Charmantier. 2020. Oxford University Press. 352 pages, 49.95 USD, Paper.

BOTANY

A History of Plants in 50 Fossils. By Paul Kenrick. 2020. CSIRO Publishing. 160 pages, 34.99 AUD, Cloth.

Aquatic Monocotyledons of North America: Ecology, Life History, and Systematics. By Donald H. Les. 2020. CRC Press. 556 pages, 260.00 USD, Cloth, 57.95 USD, E-book.

Comparative Plant Succession among Terrestrial Biomes of the World. By Karel Prach and Lawrence R. Walker. 2020. Cambridge University Press. 300 pages, 102.95 CAD, Cloth, 51.95 CAD, Paper.

Entangled Life: How Fungi Make Our Worlds, Change Our Minds & Shape Our Futures. By Merlin Sheldrake. 2020. Penguin Random House. 368 pages, 28.00 USD, Cloth, 13.99 USD, E-book.

Flore Nordique du Québec et du Labrador, Tome 3. Edited by Serge Payette. 2018. Les Presses de l'Université Laval. 711 pages, 89.95 CAD, Paper or PDF.

Tree Story: The History of the World Written in Rings. By Valerie Trouet. 2020. Johns Hopkins University Press. 246 pages, 27.00 USD, Cloth. Also available as an E-book.

CLIMATE CHANGE

Dangerous Earth: What We Wish We Knew About Volcanoes, Hurricanes, Climate Change, Earthquakes, and More. By Ellen Prager. 2020. University of Chicago Press. 272 pages, 25.00 USD, Cloth, 18.00 USD, E-book.

ECOLOGY AND CONSERVATION

Canadian Environmental Philosophy. Edited by C. Tyler DesRoches, Frank Jankunis, and Byron Williston. 2019. McGill-Queen's University Press. 352 pages, 32.95 CAD, Paper. Also available as an E-book.

And the Coastlands Wait: How the Grassroots Battle to Save Georgia's Marshlands Was Fought—and Won. A Wormsloe Foundation Nature Book. By Reid W. Harris. Foreword by Jimmy Carter. New Afterword by Charles H. McMillan III. 2020. University of Georgia Press. 136 pages, 24.95 USD, Paper.

Curious about Nature: A Passion for Fieldwork. Ecology, Biodiversity and Conservation Series. Edited by Tim Burt and Des Thompson. 2020. Cambridge University Press. 412 pages, 102.95 CAD, Cloth, 45.95 CAD, Paper. Also available as an E-book.

Global Biodiversity, Volume 4: Selected Countries in the Americas and Australia. Global Biodiversity Series. Edited by Thammineni Pullaiah. 2019. Apple

Academic Press. 574 pages, 169.95 USD, Cloth, 52.16 USD, E-book.

Handbook of Citizen Science in Ecology and Conservation. Edited by Christopher A. Lepczyk, Owen D. Boyle, and Timothy L.V. Vargo. Foreword by Reed F. Noss. 2020. University of California Press, 336 pages, 85.00 USD, Cloth, 39.95 USD, Paper or E-book.

Leaving Space for Nature: The Critical Role of Area-Based Conservation. Routledge Studies in Conservation and the Environment. By Nigel Dudley and Sue Stolton. 2020. Routledge. 194 pages, 155.00 USD, Cloth, 44.95, Paper, 40.46 USD, E-book.

Peatlands: Ecology, Conservation and Heritage. Earthscan Studies in Natural Resource Management. By Ian D. Rotherham. 2020. Routledge. 208 pages, 155.00 USD, Cloth, 44.95, Paper, 40.46 USD, E-book.

Primer of Ecological Restoration. By Karen D. Holl. 2020. Island Press. 224 pages, 35.00 USD, Paper or E-book.

Entomology

Aleocharine Rove Beetles of British Columbia: A Hotspot of Canadian Biodiversity (Coleoptera, Staphilinidae). By Jan Klimaszewski, Richard Hoebeke, Benoit Godin, Anthony Davies, Kayla I. Perry, Caroline Bourdon, and Neville Winchester. 2020. Springer. 500 pages, 249.99 CAD, Cloth, 189.00 CAD, E-book.

Butterfly Gardening: The North American Butterfly Association Guide. By Jane Hurwitz. 2018. Princeton University Press. 288 pages and 300 colour illustrations, 29.95 USD, Paper.

Charles Valentine Riley: Founder of Modern Entomology. By W. Conner Sorensen, Edward H. Smith, and Janet R. Smith, with Donald C. Weber. 2019. University of Alabama Press. 456 pages, 54.95 USD, Cloth or E-book.

Emperors, Admirals & Chimney Sweepers: The Weird and Wonderful Names of Butterflies and Moths. By Peter Marren. 2020. Little Toller Books. 282 pages, 20.00 GBP, Paper.

How Insects Work: An Illustrated Guide to the Wonders of Form and Function—from Antennae to Wings. By Marianne Taylor. 2020. Workman Publishing. 224 pages, 16.95 USD, Paper, 15.95 USD, E-book.

The Moths of America North of Mexico, Fascicle 25.4: Noctuoidea: Noctuidae (Part): Pantheinae, Raphiinae, Balsinae, Acronictinae. By B. Christian Schmidt and Gary G. Anweiler. 2020. The Wedge Entomological Research Foundation. 479 pages, 115.00 USD, Cloth.

Praying Mantises of the United States and Canada. Second Edition. By Kris Anderson. 2019. Privately published. 297 pages and 183 illustrations. 91.01 CAD from Amazon.ca.

Herpetology

Islands and Snakes: Isolation and Adaptive Evolution. Edited by Harvey B. Lillywhite and Marcio Martins. 2019. Oxford University Press. 343 pages, 120.00 CAD, Cloth. Also available as an E-book.

Ornithology

The Bird Way: A New Look at How Birds Talk, Work, Play, Parent, and Think. By Jennifer Ackerman. 2020. Penguin Press. 368 pages, 28.00 USD, Cloth.

Birds of Paradise and Bowerbirds: An Identification Guide. By Phil Gregory. Illustrated by Richard Allen. 2020. Princeton University Press. 416 pages, 45.95 USD, Cloth.

Hand-Rearing Birds. Second Edition. Edited by Rebecca S. Duerr and Laurie J. Gage. 2020. Wiley-Blackwell. 816 pages, 167.99 CAD, Cloth, 134.99 CAD, E-book.

How Birds Work: An Illustrated Guide to the Wonders of Form and Function—from Bones to Beak. By Marianne Taylor. 2020. Workman Publishing. 224 pages, 16.95 USD, Paper, 15.95 USD, E-book.

Zoology

After the Grizzly: Endangered Species and the Politics of Place in California. By Peter S. Alagona. 2020. University of California Press. 336 pages, 34.95 USD, Cloth or E-book, 27.95 USD, Paper.

Bat Roosts in Trees: A Guide to Identification and Assessment for Tree-Care and Ecology Professionals. By Bat Tree Habitat Key. 2018. Pelagic Publishing. 271 pages, 67.97 CAD, Paper.

The Book of Eels: Our Enduring Fascination with the Most Mysterious Creature in the Natural World. By Patrik Svensson. Translated from the Swedish by Agnes Broome. 2020. Ecco (HarperCollins imprint). 256 pages, 35.99 CAD, Cloth.

Red Gold: The Managed Extinction of the Giant Bluefin Tuna. By Jennifer E. Telesca. 2020. University of Minnesota Press. 312 pages, 224.95 USD, Paper.

Return to the Sea: The Life and Evolutionary Times of Marine Mammals. By Annalisa Berta. Illustrated by James L. Sumich and Carl Buell. 2020. University of California Press. 224 pages, 24.95 USD, Paper. First published in Cloth or E-book in 2012.

Rock Pool: Extraordinary Encounters Between the Tides. By Heather Buttivant. 2020. September Publishing. 288 pages, 9.99 GBP, Paper. Also available as an E-book.

Salmon: A Fish, the Earth, and the History of Their Common Fate. By Mark Kurlansky. 2020. Patagonia. 440 pages and 150 colour photos and illustrations, 30.00 USD, Cloth.

Still Water: The Deep Life of the Pond. By John Lewis-Stempel. 2019 (Cloth), 2020 (Paper). Black Swan. 304 pages, 14.99 GBP, Cloth, 9.99 GBP, Paper. Also available as an E-book.

The Wisdom of Wolves: How Wolves Can Teach Us to Be More Human. By Elli H. Radinger. 2019. Penguin Books. 256 pages, 9.99 GBP, Paper. Also available as an E-book.

THE NORTH

Brave New Arctic: The Untold Story of the Melting North. By Mark C. Serreze. 2020. Princeton University Press. 272 pages, 17.95 USD, Paper. Also available as an E-book.

Land of Wondrous Cold: The Race to Discover Antarctica and Unlock the Secrets of Its Ice. By Gillen D'Arcy Wood. 2020. Princeton University Press. 312 pages, 27.95 USD, Cloth. Also available as an E-book.

OTHER

The Field Guide to Citizen Science: How You Can Contribute to Scientific Research and Make a Difference. By Darlene Cavalier, Catherine Hoffman, and Caren Cooper. 2020. Workman Publishing. 188 pages, 16.95 USD, Paper, 15.95 USD, E-book.

Greenery: Journeys in Springtime. By Tim Dee. 2020. Jonathan Cape. 368 pages, 18.99 GBP, Cloth or E-book.

Into Russian Nature: Tourism, Environmental Protection, and National Parks in the Twentieth Century. By Alan D. Roe. 2020. Oxford University Press. 360 pages, 39.95 CAD, Cloth. Also available as an E-book.

Natural: How Faith in Nature's Goodness Leads to Harmful Fads, Unjust Laws, and Flawed Science. By Alan Levinovitz. 2020. Beacon Press. 264 pages, 28.95 USD, Cloth.

A Naturalist in the Amazon: The Journals & Writings of Henry Walter Bates. By Henry Walter Bates. 2020. Smithsonian Books. 160 pages, 23.95 USD, Cloth.

Nature's Prophet: Alfred Russel Wallace and His Evolution from Natural Selection to Natural Theology. By Michael A. Flannery. 2018. University of Alabama Press. 280 pages, 44.95 USD, Cloth or E-book.

Replenish: The Virtuous Cycle of Water and Prosperity. By Sandra Postel. 2020. Island Press. 336 pages, 26.00 USD, Paper. Cloth and E-book editions published in 2017.

Scientific Writing = Thinking in Words. Second Edition. By David Lindsay. 2020. CSIRO Publishing. 180 pages, 34.99 AUD, Paper.

Unnatural Companions: Rethinking Our Love of Pets in an Age of Wildlife Extinction. By Peter Christie. 2020. Island Press. 280 pages, 28.00 USD, Paper or E-book.

The Well Gardened Mind: Rediscovering Nature in the Modern World. By Sue Stuart-Smith. 2020. William Collins (Harper Collins imprint). 352 pages, 20.00 GBP, Cloth, 7.99 GBP, E-book.

The Canadian Field-Naturalist

News and Comment

Compiled by Amanda E. Martin

Upcoming Meetings and Workshops

Ecological Society of America Annual Meeting

Ecological Society of America Annual Meeting to be held as an online meeting, 3–6 August 2020. The theme of the conference is: 'Harnessing the ecological data revolution'. Registration is currently open. More information is available at https://www.esa.org/saltlake/.

18th Annual Symposium on the Conservation and Biology of Tortoises and Freshwater Turtles

The 18th Annual Symposium on the Conservation and Biology of Tortoises and Freshwater Turtles, hosted by the Turtle Survival Alliance (TSA) and IUCN Tortoise and Freshwater Turtle Specialist Group (TFTSG), to be held as a "virtual experience" 6 August–24 September 2020. The TSA and IUCN TFTSG, in collaboration with Zoo Med Laboratories, are making this event free of charge. More information is available at https://turtlesurvival.org/2020-symposium/.

The Wildlife Society's 2020 Annual Conference

The Wildlife Society's 2020 Annual Conference to be held as an online meeting, 28 September–2 October 2020. Registration is currently open. More information is available at https://twsconference.org/.

James Fletcher Award for *The Canadian Field-Naturalist* Volume 133

The James Fletcher Award is awarded to the authors of the "best" paper published in a volume of *The Canadian Field-Naturalist* (CFN). The award is in its fourth year. The award honours James Fletcher, founder of the Ottawa Field-Naturalists' Club (OFNC) and the first editor of CFN's earliest iteration, *Transactions of the Ottawa Field-Naturalists' Club*. A subcommittee of the OFNC Publications Committee sifted through all papers in Volume 133 of CFN, and came up with a list of the top five papers. From these top five, the committee selected the top paper. The award for Volume 133 of CFN goes to:

Andrew Campomizzi, Zoé Lebrun-Southcott, and Kristyn Richardson. Conspecific cues encourage Barn Swallow (*Hirundo rustica erythrogaster*) prospecting, but not nesting, at new nesting structures. Canadian Field-Naturalist 133(3): 235–245. https://doi.org/10.22621/cfn.v133i3.2233

- The Barn Swallow population has declined substantially in Canada since 1970 and the species is listed at Threatened by the Government of Canada. One possible cause of the decline is loss of nesting habitat. This study, conducted by researchers with Bird Ecology and Conservation Ontario and Bird Studies Canada, tests whether adding artificial conspecific cues (vocalizations and decoys) could increase uptake of artificial nesting structures by Barn Swallows. Barn Swallows were more likely to investigate nesting structures if conspecific cues were present, but these cues did not seem to encourage nesting. This study tested a simple, clear hypothesis with real-world conservation implications.

Congratulations to Andrew Campomizzi and coauthors for their excellent paper.

Honourable mentions

Annegret Nicolai, Robert Forsyth, Melissa Grantham, and Cary Hamel. Tall grass prairie ecosystem management—a gastropod perspective. Canadian Field-Naturalist 133(4): 313–324. https://doi.org/10.22621/cfn.v133i4.2217

- This paper provides results from the first thorough gastropod survey within the tall grass prairie ecosystem in Manitoba, with a focus on different habitat types and management practices used and how these affected species occurrence. Five gastropod species were newly recorded from Manitoba.

Rosemary Curley, David Keenlyside, Helen Kristmanson, and Randall Dibblee. A review of the historical and current status of American Beaver (*Castor canadensis*) on Prince Edward Island, Canada. Canadian Field-Naturalist 133(4): 332–342. https://doi.org/10.22621/cfn.v133i4.2145

- The status of beaver on Prince Edward Island (PEI) has been uncertain. This paper uses postglacial and archaeological records to show that beaver were present on PEI long before European contact, demonstrating that beavers were native to the island.

David Seburn and Hannah McCurdy-Adams. Do turtle warning signs reduce roadkill? Canadian Field-Naturalist 133(3): 216–220. https://doi.org/10.22621/cfn.v133i3.2279

- Roadkill is a major risk for many species of freshwater turtles. In this paper, the authors test the effectiveness of turtle road-crossing signs at reducing roadkill in turtles using a before-after control-impact design. The authors found no evidence of a reduction in mortality when signs were present, suggesting that this method alone may not be sufficient to reduce road mortality for turtles.

Sean Boyle, Rachel Dillon, Jacqueline Litzgus, and David Lesbarrères. Desiccation of herpetofauna on roadway exclusion fencing. Canadian Field-Naturalist 133(1): 43–48. https://doi.org/10.22621/cfn.v133i1.2076

- Road mortality is well documented as a major risk to herpetofauna. This paper shows that wildlife exclusion fencing, a common road mortality mitigation tool, might increase mortality for amphibians and reptiles. The results have important management and conservation implications.

Congratulations to these finalists. We would also like to show our appreciation to all authors who chose to share their interesting and valuable field-based studies with the readers of Volume 133 of *The Canadian Field-Naturalist*.

WILLIAM D. HALLIDAY and JEFFERY M. SAARELA
OFNC Publications Committee

Draft Minutes of the 141st Annual Business Meeting (ABM) of the Ottawa Field-Naturalists' Club, 14 January 2020

Place and time: K.W. Neatby Building, Carling Avenue, Ottawa, Ontario, 7:00 pm
Chairperson: Diane Lepage, President

Forty-six attendees spent the first half-hour reviewing minutes of the previous ABM, the financial statements, Treasurer's Report, and annual reports of OFNC committees for 2018–2019. The meeting was called to order at 7:30 pm. During the meeting, relevant documents were projected on a screen for the audience's information.

1. Minutes of the Previous Annual Business Meeting (ABM)

It was moved by Elizabeth Moore, seconded by David McNicoll, that the minutes of the 140th ABM be accepted as distributed and published in *The Canadian Field-Naturalist* (CFN).

Carried

2. Business Arising from the Minutes

Nil.

3. Communications Relating to the Annual Business Meeting

Diane Lepage noted that the Club had received a Christmas card from her Excellency the Right Honourable Julie Payette, Governor General of Canada.

4. Treasurer's Report by Ann Mackenzie

Ann MacKenzie, Treasurer, presented the Financial Statements for 30 September 2019 as prepared and reviewed by the accounting firm, Welch LLP. Copies of the complete statement as well as the written Treasurer's Report were available as hand-outs to those attending the meeting.

In the presentation Ann reviewed the basis for the substantial difference in the deficit from the previous year, 2018, to the current statements for 2019. These included the Club having given fewer donations to outside organizations, increased subscription fees for CFN, lower website costs, and a surplus from the Pelee trip. Ann then reviewed the sources of income and expenses for the year. A chart comparing with the previous year showed little change with the income from membership, donations, and interest available for general club activities. Some activities like CFN and Fletcher Wildlife Garden generate some income to offset their expenses. Overall the Club remains in a solid financial situation.

It was moved by Ann MacKenzie, seconded by Ken Young, that the Financial Statements be accepted as a fair representation of the financial position of the Club as of 30 September 2019.

Carried

5. Nomination of the Accounting Firm

It was moved by Ann MacKenzie, seconded by Ken Young, that the accounting firm of Welch LLP be contracted to conduct a review of the OFNC's accounts for the fiscal year ending 30 September 2020.

Carried

6. Committee Annual Reports

It was moved by Elizabeth Moore, seconded by Ian Whyte, that the committee reports be accepted as distributed.

Carried

7. Highlights from 2019

a) Education and Publicity (Gordon Robertson)

Gord presented several initiatives being implemented by the committee:

i) Storyboards have been erected at the Fletcher Wildlife Garden (FWG) with bilingual descriptions of examples of the flora and fauna of the garden. These are changed with the seasons.

ii) Check-box brochures have been developed for groups touring the FWG and are being created for other trails in the area.

iii) Species trail maps, e.g., for trees, are also being developed for trails in the area.

Gord expressed interest in any technology that could be used to create cellphone based species maps for local areas. He also noted that the committee needs new members.

b) SafeWings Ottawa (Anouk Hoedeman)

Anouk noted that SafeWings is becoming bus-

ier each year and is taking in an increasing number of birds for rehabilitation. Of particular note is the upcoming launch of the Ottawa Bird Strategy, a joint project with the Ottawa Valley Wild Bird Care Centre, Bird Studies Canada, Nature Canada, and the National Capital Commission. The project addresses the hazards birds experience and potential ameliorating strategies. It will be launched with the annual bird display to be held this year at the Museum of Nature on 26 March.

c) Publications (Annie Belair)

Annie was delighted to advise that all issues of *Trail & Landscape* are now archived online on the Biodiversity Heritage Library (BHL) website. This archive can be accessed through the OFNC website. Five issues of CFN were published in 2019, including the second part of the special issue titled "Studies on Canadian Amphibians and Reptiles in Honour of Dr. Francis Cook". The new CFN layout artist has updated the appearance of the publication. Annie noted that several papers published this year received media coverage. A new volunteer Book Review Editor is required.

8. Nominations for Board of Directors Positions

Fenja Brodo presented the slate of candidates nominated to the Board of Directors for 2020:

EXECUTIVE COMMITTEE

Diane Lepage	President
Jakob Mueller	1st Vice President and Chair, Events Committee
Owen Clarkin	2nd Vice President and Chair, Conservation Committee
Elizabeth Moore	Recording Secretary
Ann MacKenzie	Treasurer

DIRECTORS

Fenja Brodo	Past President
Robert Cermak	Chair, Birds Committee
Edward Farnworth	Representative, Fletcher Wildlife Committee
Catherine Hessian*	Member-at-Large
Anouk Hoedeman	Chair, Safe Wings Ottawa
Diane Holmes	Member-at-Large
Diane Kitching	Representative, Macoun Field Club
Bev McBride	Member-at-Large
Gordon Robertson	Chair, Education and Publicity
Jeff Saarela	Chair, Publications – Board Representative Annie Bélair
Henry Steger	Chair, Membership
Ken Young	Chair, Finance
Eleanor Zurbrigg	Chair, Awards

EX OFFICIO

Annie Bélair, Editor of *Trail & Landscape*
Dwayne Lepitzki, Editor of *The Canadian Field-Naturalist*

It was moved by Fenja Brodo and seconded by Ann MacKenzie that this slate of nominees be accepted as members of the Board of Directors of the OFNC for 2020.

Carried

Fenja was pleased to note that all last year's Board Members are returning and that Owen Clarkin, Conservation Chair, has also accepted the long vacant position of 2nd Vice-President. Fenja warmly welcomed Diane Holmes as a Member-at-Large, noting that her experience in municipal politics will be a valuable asset to the Club.

9. New Business and General Discussion

a) Colacem L'Orignal Cement Plant

Gord Robertson drew the attention of the meeting to the approval by the Ontario Municipal Board of the construction of a cement plant by Colacem Canada Inc. in L'Orignal, Ontario.

The Vankleek Hill and District Nature Society (VKHDNS) had requested OFNC assistance in attempting to overturn approval of the plant which will be situated close to the Ottawa River adjacent to a number of areas of ecological interest, including Alfred Bog. Colacem submits that the emissions from the proposed 125 m tall kiln will be within Ontario standards. Daniel Cloutier of the VKHDNS had presented data to the OFNC suggesting that the emissions are significantly underestimated. Furthermore, as there is no rail or water access, all materials will be delivered to and from the plant by heavy trucks. VKHDNS had requested financial support to pay an expert to validate the data gathered by the Society and also asked that OFNC consider becoming a participant in the appeal process.

b) Burnt Land's Alvar

Diane Lepage reported that the Mississippi Valley Field Naturalists' Club (MVFNC) had sought OFNC assistance in promoting protection of the Alvar which

*Catherine Hessian manages the OFNC's investments.

is under increasing threat from development and recreational use. The MVFNC is keen to develop a website to promote understanding of the importance of the Alvar.

10. Adjournment

It was moved by Elizabeth Moore, seconded by Eleanor Zurbrigg, that the meeting be adjourned.

Carried

Presentation: After the meeting was adjourned, Jakob Mueller gave a short presentation entitled "Hiding in Plain Sight: Some Conservation Discoveries in Eastern Ontario". Jakob described how, despite the dearth of reports of reptiles and amphibians east of Highway 416 on species maps, OFNC members had readily found examples in this area.

ELIZABETH MOORE
Recording Secretary

Annual Reports of OFNC Committees for October 2018–September 2019

Awards Committee

The Awards Committee manages the process to annually recognize those Ottawa Field-Naturalists' Club (OFNC) members and other qualified persons who, by virtue of their efforts and talents, are deserving of special recognition. In late 2018, nominations were received and evaluated (see awards criteria at http://ofnc.ca/about-ofnc/awards), resulting in nominees for four awards being recommended to the Board of Directors for approval. Biographies were written for each award recipient for inclusion in the Club's publications and posting on the website. The awards were presented at the annual Awards Night in April 2019. The recipients' names, type of award, and rationale for recognition follow below.

- Gregory Zbitnew—Member of the Year Award for writing an informative four-part series for *Trail & Landscape* as a tool for birders.
- Henry Steger—George McGee Service Award for managing the Club's membership program and long-time service with the Fletcher Wildlife Garden.
- Anouk Hoedeman—Conservation Award for a Member for establishing and expanding Safe Wings Ottawa including bird rescue and short-term care.
- Bill McMullen—Mary Stuart Education Award for connecting students with nature especially through photography.

President Diane Lepage selected Ann MacKenzie as the recipient of the 2018 President's Prize to recognize her efforts in guiding the Club toward financial sustainability, professionalism, and accountability.

The Awards Committee thanks Mark Brenchley for helping with awards certificate design and printing.

ELEANOR ZURBRIGG, Chair

Birds Committee

Birds Committee (11 members, one ex officio), Bird Records Subcommittee (11 members), and Bird Feeders Subcommittee (one member who coordinates and fills in when needed and five volunteers) coordinated OFNC bird related activities and directed and encouraged interest in birds within and outside the OFNC area.

A committee member administered the Ottawa Field-Naturalists' Club's Facebook group (2142 members in November 2019) which is a place for OFNC members and non-members to discuss ideas and exchange information relating to all aspects of natural history, club outings, and club initiatives, as well as for prospective members to get a feel for what the OFNC is about.

A committee member provided weekly provincial (Ontbirds) reports of OFNC area (Ottawa-Gatineau) bird sightings which with photos by local photographers was also provided on OFNC Facebook and the OFNC website.

Committee members provided articles on a variety of subjects in *Trail & Landscape*, led OFNC field trips, found volunteers to lead the 2019 Point Pelee Bus Excursion, participated in the OFNC Website Working Group and improved Birds content on the website, and responded to bird related enquires from members and the public. The Bird Studies Group organized talks and workshops on topics of interest to birders such as the Chirps, Tweets & Trills workshops which were attended by about 75 people. We coordinated updates to Department of National Defense's Shirley's Bay causeway access list which currently contains about 400 OFNC members.

Committee members conducted surveys of ground nesting species at risk, Eastern Whip-poor-will (Threatened) and Common Nighthawk (Special Concern), on Torbolton Ridge land (404 ha along Thomas A. Dolan Parkway) owned by the City of Ottawa in support of the Friends of the Carp Hills. Their Carp Barrens Trail Study is assessing the sensitivity of impact of mountain bike trail construction and use that is sensitive to the preservation of the special ecology of the Carp Hills.

OFNC Birds Committee and the Club des Ornithologues de L'Outaouais (COO) organized the 100th Ottawa-Gatineau Christmas Bird Count in December 2018 with 145 field observers in 73 parties plus 33 feeder watchers finding 75 bird species and 26056 individual birds.

Birds Committee organized and participated in the 2019 Seedathon "Big Day" birding event which was held in early fall to raise funds for the purchase of seeds for the OFNC bird feeders. 129 bird species were found and about $900 was donated.

BOB CERMAK, Chair

Conservation Committee

As in years past, the committee was busy with two main types of conservation work:

- responses to conservation issues which appeared during the year; and
- active fieldwork, with an aim to fill gaps of knowledge regarding species and habitats of eastern Ontario and southern Quebec.

Our responses to issues ranged from the conservation of particular species such as cormorants and related possible changes to hunting regulations, to proposed changes of the *Endangered Species Act* itself. For 2020, we intend to more closely monitor conservation issues such as proposed changes to legislation, to enable responses with more lead time and flexibility as topics arise.

This was a productive year for fieldwork, and the following are some highlights. We made a conscious effort to check apparently suitable habitat for reptile and amphibian species in areas of eastern Ontario for which reports were lacking, and found that "just showing up and looking" resulted in a number of significant discoveries, at least "officially". For example:

- Orleans Ravines: first Wood Frog since 1983, first record for Spotted Salamander, and confirmed presence of Blue-spotted Salamander, Eastern Red-backed Salamander, American Toad, Gray Treefrog, and Spring Peeper;
- Warwick Forest Conservation Area: first records for Eastern Garter Snake and Midland Painted Turtle; and
- Summerstown Forest: first records of Eastern Red-backed Salamander, Eastern Garter Snake, and confirmed presence of Blue-spotted Salamander.

Similar significant discoveries occurred during field trips to sites such as Green's Creek, Garry Fen, Carlington Park, and the Carp Hills.

Special thanks to committee member Jakob Mueller for leading our herpetological survey effort this year, and for being the driving force behind its success. For 2020 we intend to build on this work with another focussed campaign, and search for new species such as Mudpuppies.

We searched for, and came up empty-handed, looking for the S1-ranked shrub Rhodora this spring but will look again in 2020 with more organization and anticipated success.

We discovered that the Red Spruce belt of eastern Ontario is even larger than surveys in previous years had indicated, with apparently suitable habitat found throughout Cumberland Forest, and new populations of this S3-ranked species were discovered east of Vars in autumn 2019. Over the winter of 2019–2020 we will finish our push to complete our main work on the multi-year "Red Spruce / Acadian Forest in eastern Ontario" project.

During the course of the year we also found new records of apparent significance for a variety of plant species, such as:

- in eastern Ontario: American Hazelnut (Constance Bay), Southern Arrowwood (Cumberland Forest), Balsam Willow (Bourget), and Dwarf Strawberry Bush aka *Euonymus nanus* (Gillies Grove); and
- in southern Quebec: using the 2009 publication "Plantes Rares du Québec Méridional" as a guide, new records of many species were documented including Rock Elm, Hackberry, Butternut, Wild Ginger, American Plum, and Bur Cucumber.

We also (painfully) discovered that Fire Ants had appeared at two sites along the Ottawa River, including the MacSkimming Outdoor Education Centre.

In 2019 we began to focus on exploring specific habitat types threatened by resource exploitation, such as bogs (peat extraction) and limestone uplands (quarrying); we plan to continue and expand upon this theme into 2020.

OWEN CLARKIN, Chair

Education and Publicity Committee

Storyboards continue to be developed. Seven new ones added. Stories were rotated every season.

We held a third Open House at the Resource Centre in collaboration with Jane's Walks. Several members hosted about 100 visitors with drinks, cookies, and tours of the garden. This was approximately the same number of people as the previous year.

This year we had only one application for sponsorship to the Youth Summit of Ontario Nature. The candidate was judged worthy to attend the summit. Kathy Conlan, Diane Lepage, and Gordon Robertson were judges at the annual Ottawa Regional Science Fair. They awarded four OFNC awards ($100 each) and one-year club memberships to the winning students.

We hosted numerous group tours of the Fletcher Wildlife Garden this year including one tour for home schoolers, three tours for Scouts/Beavers/Brownies, and two tours for school groups. We also developed several new Visual/Audio Scavenger Hunts for use with these groups at Petrie Island and several Mer Bleue trails.

Presentations were given to the Kanata Seniors Centre Camera Club, which had about 50 attendees and a kindergarten class at St. Marguerite d'Youville. Lynn Ovenden and Gia Paolo hosted our booth at the Wildlife Speaker Series in May.

Finally, we had lost several members and only gained one new member, Ms. Beesan Sarrouh. Ms. Gia Paola continues to help out at our events despite being a non-member.

GORDON ROBERTSON, Chair

Events Committee

The 2019 Events Committee coordinated 62 events, consisting of field trips, workshops, and presentations

for monthly meetings. With challenging, late spring weather and a prolonged flood on the Ottawa River, a number of events were postponed, but were ultimately held on new dates; only one event (not counted in the 62) was cancelled. Among the other events, after a two-year hiatus, a multi-day excursion to Point Pelee and Rondeau was held in May.

Each of the Club's 10 monthly meetings included a presentation. Nine of these were the feature event of the meeting, while the January ABM included an abbreviated presentation. The diverse topics included forest ecology (salamanders, urban trees, and mycorrhizae), conservation challenges (Monarch Butterflies, road ecology, Chronic Wasting Disease, and microplastics), the application of field biology (fish surveys and genetics in birds), and a travelogue (wildlife in Japan).

Topics for the various trips and workshops included birding (20), fungi (seven), herpetology (five), botany (four), entomology (four), photography (four), molluscs (one), and geology (one), with the remainder being general interest (10). (Four trips fit more than one category, not including general interest.)

The committee extends its sincere gratitude to all individuals who lead, presented, or assisted with events. While all volunteers are too numerous to mention, the committee would like to extend a special thank-you to a few OFNC members who are not part of Events: Martha Farkas, who acted as trip coordinator on the fabulous Point Pelee excusion, and Joan Heyding, Lynn Ovendon, and Brett Stevens, who were instrumental in adding much-needed content related to fungi.

Finally, the Chair would like to commend and thank Julia Cipriani, a stalwart member of the Events Committee, for the tireless effort and guidance she has provided over many years.

JAKOB MUELLER, Chair

Finance Committee

This report covers financial matters during fiscal year 2018–2019, which extended from 1 October 2018 through 30 September 2019. Many of these matters go directly to the Board of Directors for resolution. However, they are mentioned here to give OFNC members a sense of the financial issues that occur.

The primary task of the Finance Committee is to prepare a draft budget for consideration by the Board of Directors. The Finance Committee receives suggestions, and expected revenues and expenses from Board of Directors members and committee chairs. The budget for FY2018–2019 was approved at the Board of Directors meeting of October 2018. The draft budget for FY2019–2020 was presented to the Board's September 2019 meeting. After discussion, a revised version was approved at the October 2019 Board meeting. The budget forecasts revenues of $129 800, expenses of $153 550, for a deficit of $23 750. A copy of the budget, as approved, is included as an appendix to the minutes of the October 2019 Board of Directors meeting. These minutes are posted on the OFNC website (https://ofnc.ca/wp-content/uploads/2019/11/OFNC-Board-Minutes-2019-10-22.pdf).

The question arises from time to time whether our spending is appropriate. Members have two concerns. On the one hand, will we exhaust our investment fund prematurely? A member of the Board and the Finance Committee, Catherine Hessian, has projected our financial situation into the future. Using deficit figures higher than we are actually running ($75 000 or $100 000) and interest rates of 2%, 3%, or 4% (currently we are earning 3%), our investment fund will be maintained for between 16 and 37 years. Based on this, the Board feels that our deficits are reasonable.

The other concern is that we are not spending enough. The Board of Directors reviews proposals for spending, during the budget process and on an ad hoc basis during the year. Proposals are evaluated based on the Club's objectives, for example natural history education, and our policies, for example a focus on eastern Ontario and the Ottawa Valley. The Board is responsive to proposals, but also prudent.

During the 2018–2019 fiscal year, the Board dealt with several additional financial issues:

- a policy on accepting advertisements in *Trail & Landscape*;
- a policy on mileage rates—who was eligible and what rate to use; and
- a proposal to support financially a bird observatory, not in the Ottawa area, was discussed but not approved.

The Treasurer continued her work to improve our systems for bookkeeping, donations, and payments.

KEN YOUNG, Chair

Fletcher Wildlife Garden

The wet cold spring delayed the season for volunteer work at the Fletcher Wildlife Garden (FWG), and throughout the spring and summer the growth of many flowers, shrubs, and trees was slow. However, the dedication of our volunteers ensured that visitors to the garden were able to enjoy the many plants, trees, insects, amphibians, and mammals that inhabit the property.

Our plant sale, which was held in early June, attracted more customers this year than ever before, in part due to advertising in community newsletters circulated by two local city councillors. The sale is our

biggest source of revenue. For many of our customers, it is their first visit to FWG.

The Backyard Garden continues to be one of the most visited parts of the site. This year we got to see the benefits of the work put in last year to complete a fern bed. Many of the flowers were blooming later than usual, but their arrival soon attracted a wide variety of pollinators. The bird feeder was a popular place for a large number of birds that in turn attracted many regular visits by photographers/birders.

Our Facebook page saw a lot of activity this summer. Almost daily, spectacular pictures of birds, small animals, insects, reptiles, and flowers showed the wide biodiversity to be found at the FWG.

Our three main volunteer work groups—Tuesday afternoon, Wednesday evening, and Friday morning—were kept busy maintaining the property's plants, shrubs, and trees as well as continuing our battles against Dog-strangling Vine (DSV), Buckthorn, Comfrey, and Burdock. Several areas of the garden are now relatively free of noxious and invasive plants, which have been replaced with indigenous plants. Node workers, who adopt part of the FWG, have created a new native flower bed at the entrance to the FWG and expanded the regeneration of the "gully".

Several groups from government departments, public institutions, private companies, and post-secondary faculties came to the FWG as part of their community service and outreach programs. The work by these groups on resurfacing pathways, clearing DSV, preparing new beds, and maintenance around the pond helped us to make improvements in large areas of the property.

We put in over 4700 hours of volunteer work this season. Ten percent of this was provided by external groups.

The recent addition of bilingual story boards at various locations throughout the FWG has made a valuable contribution to our mandate to educate the public. The story boards are updated regularly to keep up with the seasonal changes. We have also expanded our brochure collection. The new brochures can be used by visitors as they walk along our paths to easily identify various conifers, deciduous trees, shrubs, and vines.

In terms of community outreach, the FWG presented workshops and talks on pollinator gardens, bees, Monarch Butterflies, and wasps. As a member of Wild Pollinator Partners (WWP), the FWG hosted a colloquium in early March, bringing together 35 organizations and individuals to exchange information on pollinator habitat, identification, and conservation. The FWG also donated plants for new pollinator gardens at several schools, churches, and a library. In collaboration with the University of Ottawa, we also conducted pollinator surveys at community gardens (and the FWG) and set up an iNaturalist project to collect pollinator data in our region.

Also, as part of WPP, the FWG was instrumental in the city's presentation of a wildlife speaker event on pollinators this spring, the establishment of a pollinator garden at City Hall, and the mayor's proclamation of Pollinator Appreciation Day.

TED FARNWORTH, Committee Member

Macoun Club

The Macoun Field Club for children and young people (ages 8 to 18) runs every Saturday through the school year, except for public holidays. Indoor meetings at the Fletcher Wildlife Garden's resource centre alternate with field trips. During 2018–2019, Committee Members organized and oversaw 18 indoor meetings, with presentations and workshops, and led 14 field trips. The two principal locales for field-trips, the Club's "Study Area" in Stony Swamp and "Pakenham" in Lanark County, have been regular Macoun Club destinations for 50 years. A special field trip took the group to the Ecomuseum in Montreal by bus.

For the third time, the Macoun Club hosted the nature quiz at the OFNC's Awards Night event.

An up-to-date record of all Macoun Club activities was maintained on the OFNC website by Committee members. A Macoun Club member took on the editorship of the Club's newsletter, and renamed it *The Macoun Monthly*. It was made available online to members for the first time, too. As always, Issue No. 73 of the Club's annual magazine, *The Little Bear*, was made available to members in hard copy only.

ROBERT E. LEE, Chair

Membership Committee

This report for 2019 is presented in a different format than in previous years in two aspects. First, non-Canadian memberships are not reported by type because they represent only 1% of total membership.

Second, the total membership of previous reports is divided into two groups. The first consists of those who pay club fees, or are "Honorary" members or participate in the "Macoun Club". This group is defined as the "Membership". The other consists of the membership aggregate "Other" which represents mostly designated individuals and affiliate organizations that receive complimentary copies of the *Trail & Landscape* (T&L). They have a mission-oriented partnership, not a financial relationship, with the Club. This group, together with "T&L Subscriber" are reported separately.

The distribution of Club membership for 2019 on 30 September 2019 and on 30 September 2018 is shown in the table below. The increase in membership observed for 2019 continues the trend of long-terms gradual growth but with annually noted increases and decreases in membership.

Members within 50 km of Ottawa comprised 747 of the total membership of 860.

	2019	2018
Individual	402	384
Family	339	314
Student	30	23
Honorary	24	24
Life	39	40
Macoun Club	17	15
USA	7	9
International	1	2
TOTAL	859	811

The distribution of "Other" Club relationships for 2019 on 30 September 2019 and on 30 September 2018 is shown in the table below. The decrease arises because counting the distribution of T&L within the Club as "Other" has been halted.

	2019	2018
T&L Subscriber	3	3
Other	23	24
TOTAL	26	27

HENRY STEGER, Chair

Publications Committee

The Publications Committee manages publication of *The Canadian Field-Naturalist* (CFN), T&L, and Special Publications. The committee also advises OFNC with respect to issues relating to research, including managing the research grants program.

Trail & Landscape

Five issues of T&L were published: 52(4) and 53 (1–4). In collaboration with the Canadian Museum of Nature, major progress was made in completing imaging and uploading of T&L back issue content to the Biodiversity Heritage Library. As of 30 September 2019, content up to the end of volume 34 (2000) was freely available on the site: https://www.biodiversitylibrary.org/bibliography/115961#/summary.

The Canadian Field-Naturalist

Four issues of CFN were published: 132(1–4). Issues 132(1) and 132(2) comprised a two-part special issue titled "Studies on Canadian Amphibians and Reptiles in Honour of Dr. Francis Cook". The 24 papers published in the special issue (parts I and II) were handled by Guest Editors Dr. William Halliday and David Seburn.

Several papers published this year received media coverage, reflecting not only the important contributions to science published in the journal but also the importance and relevance of the journals content to broader society in Canada. Papers reported on include studies of life history of pair bonding in Canada Geese (https://doi.org/10.22621/cfn.v132i3.1966; Ottawa Citizen, 20 April 2019); the status of the amphibians and reptiles of Essex County, Ontario (https://doi.org/10.22621/cfn.v132i2.2053; CTV Windsor, 7 March 2019); and Snapping Turtle oviposition in asphalt (https://doi.org/10.22621/cfn.v132i2.2035; Ottawa Citizen, 22 April 2019). Some papers published in earlier years also received media attention, including studies of road mortality of wildlife in southern Ontario (https://doi.org/10.22621/cfn.v130i1.1804; Windsor Star, 21 August 2019; CTV Windsor, 24 July 2019); Beavers feeding on salmon carcasses (https://doi.org/10.22621/cfn.v119i4.215; National Post, 10 January 2019); and coyote breeding range in the Northwest Territories (https://doi.org/10.22621/cfn.v120i1.248; Northern News Services, 20 June 2019).

Ottawa Field-Naturalists' Club Research Grants

2019 was the fifth year of the Ottawa Field-Naturalists' Club Research Grants program. Research grants support field-based research activities that reflect and promote the Club's objectives within eastern Ontario and/or western Quebec, focussed particularly upon the Club's study area. A total of $15 000 is available each year to fund research proposals. The application deadline was 15 January 2019. A subcommittee convened and chaired by Dr. Jeff Saarela reviewed all proposals and submitted funding recommendations to the OFNC Board of Directors. A list of recipients of 2018 Research Grants was published in *Trail & Landscape* 53(3): 162–163.

JEFFERY M. SAARELA, Chair

Safe Wings Ottawa

From 1 October 2018 to 30 September 2019, Safe Wings Ottawa (SWO) volunteers:

- monitored 75+ buildings during spring and fall migration;
- documented 3549 window collisions;
- rescued 769 live birds following window collisions;
- provided short-term care to 914 birds, including 558 window collision victims;
- answered more than 3000 phone calls; and
- provided rescue assistance and/or transportation for hundreds of injured birds.

Our outreach efforts to encourage bird-friendly measures for existing and new buildings yielded mixed results in 2018–2019. The Canadian Museum of Nature, National Gallery of Canada, Canadian Wildlife Federation, Federation of Canadian Municipalities, and Agriculture and Agri-food Canada were among the property owners/operators to apply retrofit measures to some of their windows. Others, including KRP, the major property owner in Kanata North, declined to make any changes. As the building and its grounds are almost entirely inaccessible to outsiders, staff at Communications Security Establishment began their own monitoring program, and began prioritizing and securing funding to retrofit the most lethal façades.

The City of Ottawa failed again to deliver its overdue bird-friendly design guidelines. The working group, of which SWO is a member, was told to expect a draft in early 2020. In Kingston, Queen's University committed to adopting bird-friendly guidelines for new buildings thanks to an extra push from local allies. The owners of the Chateau Laurier sought our input to make the proposed hotel addition safer for birds, and we participated in public workshops for the design of the new central library, and for the National Capital Commission (NCC) Sustainability Strategy.

SWO attracted public attention and media coverage after raising concerns that Ottawa's new light rail transit stations, as well as those planned for Phase 2, would be lethal to birds, despite assurances from OC Transpo that bird-friendly design had been considered. In a separate initiative, we began working with OC Transpo on a pilot project to retrofit three bus shelters with Feather Friendly. The planned September launch was postponed until spring. OC Transpo staff began investigating ways to make new bus shelters bird-friendly.

We finalized the Ottawa Bird Strategy, a guiding document produced in partnership with the NCC, Nature Canada, Bird Studies Canada, and the Ottawa Valley Wild Bird Care Centre (OVWBCC). It will be officially launched in 2019–2020. We redesigned our bilingual paper rescue bags and produced a printed handout aimed at people working in hazardous buildings.

The addition of a new volunteer doubled the number of permitted rehabbers providing short-term care in their homes, one in the Glebe and one in Orleans. The OVWBCC reduced the hours during which we could transport birds to them, which increased both the number of birds admitted to our care (instead of being transported directly to the OVWBCC), and the amount of time birds remained in our care. With decreasing access to the OVWBCC, we built relationships with other rehabilitators across North America to access advice and other resources. We arranged for the City of Ottawa to cover the cost of euthanasia for badly injured birds when required at the Ottawa Animal Emergency and Specialty Hospital.

In the spring, we acquired equipment to provide oxygen therapy to birds with head trauma or respiratory distress. This treatment, along with our ability to offer after-hours care and a quieter environment for injured birds, contributed to improved outcomes. Among 2018–2019 window collision victims whose outcomes are known, 52% of birds treated solely by the OVWBCC were released, compared with 62% of those treated by SWO (whether or not they received further care at the OVWBCC).

Since 2014, SWO has documented collisions by 131 bird species, including 13 Species at Risk.

Anouk Hoedeman, Chair

Treasurer's Report

Overall—The OFNC continues to be in a solid financial situation. Despite the generous bequest from Violetta Czasak we are watching our revenues and expenses to ensure that we continue on a sustainable basis. Many organizations such as ours are experiencing declining membership and scientific journals are losing subscribers. Our membership is holding steady. We are watching our subscription renewal levels to be alert to any significant declines.

Reduced deficit—The most notable aspect of our 2019 financial statements is that the deficit has declined from \$42 870 in 2018 to \$3012 in 2019. While there are the usual ups and downs in revenues and expenditures from one year to the next there are four major contributors to the \$39 000 change this year.

\$15 500—Donations from the OFNC to other organizations were down this year. We continue to provide \$5000 to the Ottawa Carleton District School Board to allow more children to attend the outdoor centres. In 2018 we had also provided \$10 000 toward the publishing of the Birds of Nunavut, \$4500 to the Innis Point Bird Observatory, and \$1000 to the Invasive Plant Council

\$17 500—The size of the CFN deficit decreased from \$30 248 in 2018 to \$12 700 in 2019. This can vary depending on the relative match between revenues and expenses in the fiscal year. This year also reflects increased subscription rates for Volume 132.

\$3000—Website—In 2019 we switched to a new web service provider and we did not have re-design costs.

\$3000—Pelee Trip—The Club trip to Point Pelee realized a surplus.

Publications—CFN increased subscription prices for institutions for Volume 132 (2018). Since that volume was issued in 2018–2019 there is a noticea-

ble increase in subscription revenues in the 2019 fiscal year. Renewals for Volume 133 (2019) have been slow coming in. That may be because the first issue of Volume 133 was issued in September 2019. We will need to watch carefully to see if there is a real decrease in subscription revenues or if it is just a timing issue. The CFN is making progress in catching up to its schedule (the first issue of a volume should be published in the first calendar quarter). The more the CFN gets caught up to date the better the match of revenues and expenses for issues within the fiscal year.

Author Charges also show an increase since four issues were mailed during the fiscal year. About one third of the author charges are paid by the Manning Fund. Expenses are decreasing somewhat with a new contract for journal production reducing costs and speeding up production. More copy editing is being done on a volunteer basis which also reduces costs. A hard copy edition is still printed (350 copies) accounting for about 30% of the total volume cost.

Trail & Landscape does not generate revenue although it is now able to accept ads. This quarterly members magazine has been revamped giving it a more modern and lively appeal. Steps are being taken to reduce the cost ($21 644 in 2019, $23 778 in 2018, and $29 292 in 2017) without sacrificing the much appreciated quality improvements.

Fletcher Wildlife Garden—The FWG is a major activity of the Club and there is a separate fund for it showing revenues and expenses. The primary fundraiser is the plant sale which is making more money each year ($6736 in 2019, $4416 in 2018). Taking credit cards is contributing to this boost in sales. In addition they are providing plants to other charities such as Ontario Nature and the Canadian Wildlife Federation. Some donations to the OFNC are also earmarked for the FWG. While there are regular, routine expenses sometimes there are major projects such as the erosion control ditch with expenses spread over both 2018 and 2019.

Pelee trip—In May 2019 the Club organized a trip to Point Pelee for the peak of bird migration. The trip took in $26 850 in revenue and had $23 745 in expenses for a gain of $3104.57. The trip is usually offered every two years if volunteers are available. It has previously been run on a break-even basis but this year it made a profit. Given the extensive amount of volunteer time required, consideration is being given to designing future Pelee trips as fund raising events.

Safe Wings—Safe Wings is an initiative of the Club that works to reduce bird mortality from window collisions through research, prevention, and rescue. Their direct involvement with the public, many of whom are not members of the Club, results in substantial donations earning over $5000 in 2019 and about $6000 in 2018. The amount of work being undertaken has risen rapidly. In 2019 the expenses of the operation were about $6000 which was an increase from $3700 from 2018. This does not include work on a Bird Strategy funded by a grant from the City of Ottawa.

ANN MACKENZIE, Treasurer

Approved financial statements available online at: https://www.canadianfieldnaturalist.ca/index.php/cfn/article/view/2581/2445

The Canadian Field-Naturalist

The Ottawa Field-Naturalists' Club Awards for 2019, presented February 2020

Eleanor Zurbrigg, Irwin Brodo, Julia Cipriani, Christine Hanrahan, Lynn Ovenden, and Karen McLachlan Hamilton

On 22 February 2020 members and friends of the Ottawa Field-Naturalists' Club (OFNC) gathered for the Club's Awards Night at St. Basil's Church in Ottawa to celebrate the presentation of awards for achievements in the previous year. Awards are given to members or non-members who have distinguished themselves by accomplishments in the field of natural history and conservation or by extraordinary activity within the Club. Four Club awards were presented for 2019, for: (1) outstanding organization of the Club's five-day bus excursion to Point Pelee National Park, (2) worthy service including as the Book Review Editor for *The Canadian Field-Naturalist*, (3) revitalizing the Conservation Committee and promoting conservation of regional forests, and (4) habitat preservation in the Ottawa Valley.

Member of the Year: Martha Farkas

Each year, the Ottawa Field-Naturalists' Club recognizes a Club member whose exceptional accomplishments during the past 12 months stand out from the crowd. For 2019, that would surely be Martha Farkas, in recognition of her leadership on the remarkable May birding trip to Point Pelee National Park and Rondeau Provincial Park.

Why was the 2019 trip remarkable? Every other year for many decades, the OFNC has been organizing and running trips to Point Pelee in Essex County, Ontario, to observe the spring bird migration over a long weekend in May. This past year was special because there had been a three-year rather than two-year hiatus and the number of participants rose to close to 40, with the need for three birding leaders instead of two. In addition, the trip was to be a five-day event instead of the usual four days (including travel time). Finding an administrative leader who is not only willing to put in the large amount of time and effort required to make such a trip happen, but with the skills required to make the trip a success, is not always easy. The Club found just such a person for the 2019 trip, Martha Farkas, who had already learned some of the ropes by leading the previous Pelee trip.

Martha looked after all the administrative details for the excursion, starting two years before the event by reserving rooms for the entire group at a motel in Leamington, close to the park. Martha also arranged for the bus and driver months in advance. All the payments and purchases were also dealt with by Martha, looking after last-minute changes, fees, non-payments, and inevitable questions. Taking care of the financial issues is something not all Pelee trip organizers have had to do. After the all-day bus trip, and after the participants were settled at the motel, she organized the shopping for picnic lunches and later devised a way for people to put the picnic lunches together and do the required clean-up. Needless to say, she had to constantly keep track of over 35 excited and preoccupied birders both in the field and back at the home base. Always attentive to important details, Martha also brought a generous number of snacking options and water for the bus rides and was very aware of the necessity of mini-breaks on a bus with one washroom!

As one participant noted, "Martha is the consummate diplomat dealing with people. She ensured that everything ran smoothly over the three days [in the field]. She was very good at managing the movement of the participants. She stayed calm, kept order with ease while managing the schedule".

It is therefore our pleasure to recognize Martha Farkas as our Member of the Year for 2019.

(Prepared by Irwin M. Brodo and Julia Cipriani)

George McGee Service Award: Barry Cottam

This award is given in recognition of a member who has contributed significantly to the smooth running of the Club over several years.

Like many who gravitate to the Ottawa Field-Naturalists' Club, Barry's fascination with the natural world came at an early age. He quickly learned that the outdoors offers an inexpensive, endless source of learning and enjoyment. He was, and still is, never bored. He learned of the Club initially through the Fletcher Wildlife Garden (FWG), a place a friend suggested he should "check out". That was the beginning of his nine-year adventure.

Barry really loves books. So, when *The Canadian Field-Naturalist* (CFN) needed a new Book Review Editor, the position seemed a natural fit. His primary responsibility is to manage the Book Reviews and New Titles sections seen at the end of every issue. Approximately 150 books have passed through his hands since assuming the position in 2016. Most are forwarded to reviewers; however, for books that may seem a little obscure or do not seem to fit a particular niche, Barry has risen to the challenge and reviewed them himself. His reviews have included topics such as Passenger Pigeons, enlightened naturalists, human enlightenment through nature, and climate change.

Being a Book Review Editor is not for the faint of heart. It requires good communication and editing skills, and the ability to organize and coordinate every item through the review process in a timely fashion.

This process can take 20–48 hours a month to accomplish, depending on the complexity of the situation. Barry has also introduced a new twist to each review by adding a thumbnail image of the cover page. It is his natural curiosity, self-motivation, and easy-going personality that make him the editor he is.

It should be said that Barry's activities in the Club have not been restricted to CFN. When affiliated with the FWG, he served on its committee for four years, and led a small group attempting to rid the garden of Dog-strangling Vine. He was also FWG's representative to the Central Experimental Farm Advisory Committee and Friends of the Farm for two of those years. He served on the Board of Directors not only as FWG chair, but later as the OFNC representative to Ontario Nature. He left the Board in October 2016 to join the Publications Committee as Book Review Editor for CFN and Proofreader for *Trail & Landscape* (T&L). Other activities include six years as co-organizer of the Members' Photography Night and he occasionally contributes to the blog notes and T&L.

As Barry is seriously considering living full time in Prince Edward Island, his active service will be winding down. With this in mind, the Club would like to acknowledge his invaluable contributions in general and to CFN specifically. Thank you, Barry, for a job well done.

(Prepared by Karen McLachlan Hamilton)

Conservation Award—Member: Owen J. Clarkin

This award recognizes an outstanding contribution by a member in the cause of natural history conservation in the Ottawa Valley, with particular emphasis on activities within the Ottawa District.

Eight years ago, for lack of a chairperson, OFNC's Conservation Committee was relatively inactive. Contact was mainly through intermittent emails. In October 2012, Owen offered to chair regular meetings to rebuild the committee. Owen brought energy and inspiration along with agendas, minutes, and ideas to Committee meetings. New members joined. A conservation program of advocacy, public outreach, and eco-inventories evolved.

Under Owen's influence and aided by other members, the Conservation Committee identified various issues on which they made submissions on behalf of the OFNC. For example, they sent comments to Ontario's Environmental Registry on the proposed hunting of Snapping Turtles and Double-crested Cormorants, to the federal government on recovery plans for endangered turtles and American Eels, and to the City requesting sloping curbs for turtle hatchlings at Mud Lake and less mowing of meadows to support pollinators.

This advocacy for conservation has been balanced by ambitious public outreach. As Owen wrote in his 2015 Annual Report about the Conservation Committee, "We are keen to share our collective expertise with local nature lovers". Since 2012, he has led about 125 nature walks for over 20 groups, from naturalist organizations to community groups to horticultural societies. With boundless good humour, he tells people how to distinguish woody plant species by their buds, leaf venation, even their profile in the canopy on the horizon, plus information on their unique ecology. Tree Fest Ottawa described him as "Tree Educator, Activist, Treebadour".

From the beginning, one of Owen's personal goals for the Committee has been to learn the current status of uncommon or declining native plants in eastern Ontario and western Quebec. The Committee discusses and plans actions regarding species of conservation concern (both threatened indigenous species and emerging potentially invasive exotics).

They have collaborated with several organizations on bioblitzes and inventories. Most recently, Owen conducted a tree inventory of Petrie Island with the Friends of Petrie Island and the Ottawa Stewardship Council. Under Owen's leadership, the group discovered several populations of extant Red Spruce throughout Eastern Ontario and noted other species growing in Red Spruce stands. Owen has also documented the region's threatened Rock Elm.

Owen leads and keeps the Conservation Committee together. He has developed effective positions on conservation issues for the OFNC Board and collaborated with almost every conservation group in the region. He is distinguished by his generosity in sharing knowledge with others, using education as a tool to promote appreciation and conservation of nature.

It is for revitalizing the Conservation Committee and promoting appreciation and conservation of regional forests and natural areas that the OFNC is pleased to present Owen Clarkin with the 2019 Conservation Award for a Member.

(Prepared by Lynn Ovenden)

Conservation Award—Non-Member: Mississippi Madawaska Land Trust

This award is given in recognition of an outstanding contribution by a non-member in the cause of natural history conservation in the Ottawa Valley, with particular emphasis on activities within the Ottawa District.

This year, the award is given to the Mississippi Madawaska Land Trust (MMLT) in recognition of their exceptional work protecting valuable wildlife habitat.

The MMLT was founded in 2003, and soon joined the Ontario Land Trust Alliance, adopting their Canadian Land Trust Standards and Practices. Without doubt, one of the best and most enduring ways to protect our native flora and fauna is to preserve habitats in perpetuity. The MMLT focusses on acquiring and protecting land in the Ottawa Valley just west of Ottawa, within the Mississippi River and lower Madawaska River watersheds. Their Mission Statement sums up their goals nicely: "To legally protect and steward private lands having ecological, biodiverse, aesthetic, and cultural value and to foster engagement with wilderness".

The land trust approach fits in well with this objective. Land trusts "are charitable organizations which are legally empowered to protect lands worthy of long-term conservation". The MMLT protects land in several ways: by accepting donations of land, by entering into conservation easements with landowners, and by outright purchase of land. At present, the MMLT stewards eight properties encompassing a diversity of habitats from forest to wetlands, meadows, and mountains. Four of these properties are open to the public for nature viewing, hiking, and snowshoeing.

Maintaining a land trust such as the MMLT requires considerable time and effort. While there is one paid part-time staff person, everything else is conducted by dedicated volunteers (a comprehensive Volunteer Handbook delineates the many important ways in which volunteers can assist). Acquiring a property is the essential first step, followed by the preparation of maps and extensive documentation of the acquisition to satisfy legal requirements. Complete ecological assessments are also undertaken for each property including surveys of fauna and flora. As part of this process, the MMLT added an innovative acoustic monitoring of some sites during 2018. Plans are then prepared for ongoing monitoring and stewardship.

There are many costs associated with running such an organization. Financing is needed for legal fees, land appraisal, insurance, property taxes, and annual audits, and of course where applicable, buying land. Donations and membership fees contribute a significant amount. MMLT also applies for grants from various agencies for special projects, such as tree planting, the above acoustic monitoring, as well as to assist with the costs of land purchase. The MMLT holds their annual *Go Wild Gala* each autumn, with a silent auction which helps generate considerable funding. A wonderful array of guided walks and other events are held for which a modest fee is charged. There are hikes to see the fall colours on one of their most stunning properties, Blueberry Mountain, and excursions to other properties to discover lichens, watch birds, learn about wildflowers, search for dragonflies, and there is the delightfully named *Festival of the Wild Child*.

The MMLT is a dynamic, energetic, engaged group, completely dedicated to their vision of "wilderness protected for all time, where all species thrive and people engage with nature". They have been wonderfully successful in their relatively short time as a land trust and it is clear that they will continue to promote the joys and the beauty of nature as they protect yet more wild lands in the years ahead. For all of these reasons and for so much more, we are honoured to present the MMLT with the OFNC's 2019 Conservation Award—Non-Member.

(Prepared by Christine Hanrahan)

THE CANADIAN FIELD-NATURALIST **Volume 134, Number 1** **2020**

(continued inside back cover)

ISSN 0008-3550

Tributes

Book Reviews

News and Comment

Mailing date of the previous issue 133(4): 9 June 2020